Instruments

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Measurement and Control

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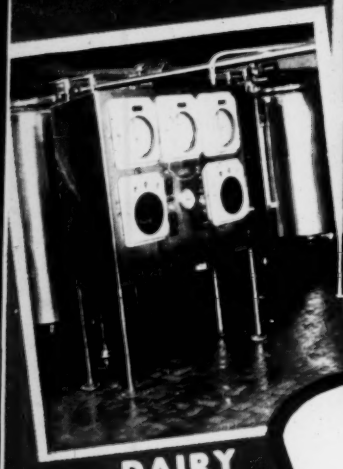
No. 1

TENTH ANNIVERSARY ISSUE • IN TWO PARTS • PART ONE



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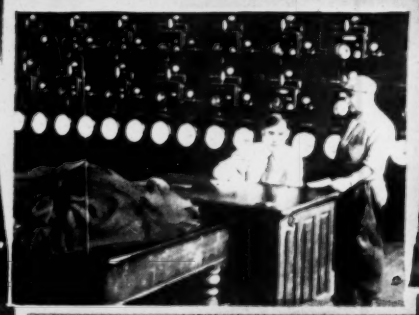

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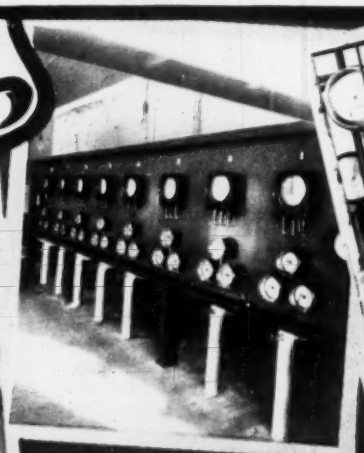

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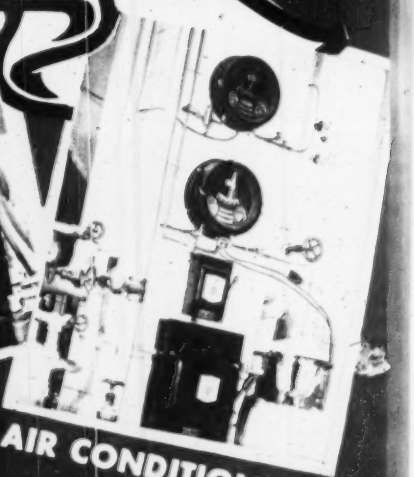

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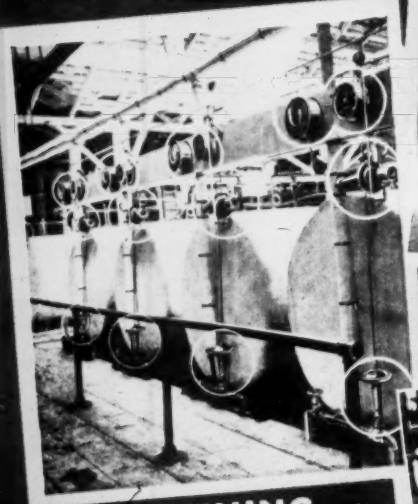

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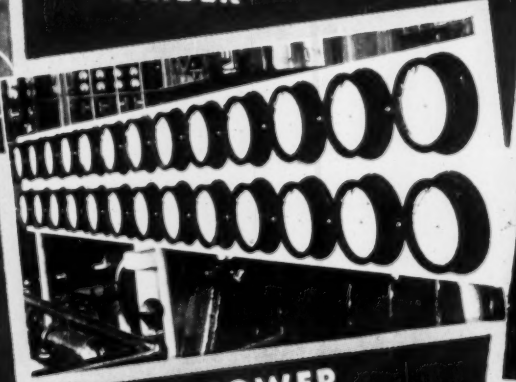

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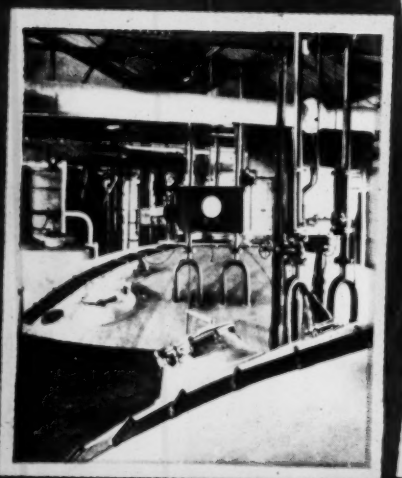

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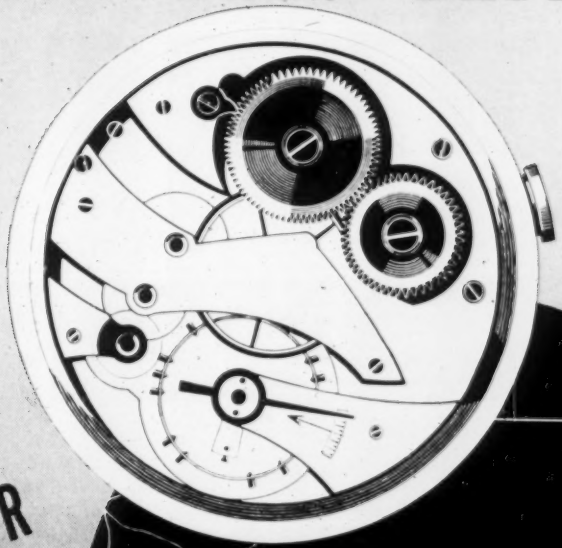

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VOL. 11 No. 1 — January, 1938 — PRICE $2.00

TENTH ANNIVERSARY ISSUE—IN TWO PARTS — BOUND SEPARATELY

CONTENTS of PART ONE

A DECADE of PROGRESS in **Temperature and Humidity Measurement and Control** — By R. D. Webb — 3

A DECADE of PROGRESS in **High Temperature Measurements** — By M. F. Behar — 8

A DECADE of PROGRESS in **Pressure Measurement and Control** — By P. G. Exline — 10

A DECADE of PROGRESS in **Industrial Fluid Metering and Automatic Control** — By R. J. S. Pigott — 19

A DECADE of PROGRESS in **Weighing and Proportioning** — By M. G. Mastin — 27

A DECADE of PROGRESS in **Electrical Instrumentation** — By E. S. Lincoln — 31

A DECADE of PROGRESS in **Shop Measurements and Inspection** — By R. W. Carson — 36

A DECADE of PROGRESS in **Physical and Chemical Testing** — By H. D. Churchill — 39

A DECADE of PROGRESS in **Industrial X-ray Inspection** — By C. S. Barrett — 41

A DECADE of PROGRESS in **Laboratory Apparatus** — By Arthur Schroder — 43

A DECADE of PROGRESS in **Time Instrumentation** — By M. F. Behar — 47

A DECADE of PROGRESS in **Cathode-ray Oscillography** — By R. R. Batcher — 49

A DECADE of PROGRESS in **Industrial Electron Tubes** — By H. B. Jenks — 50

A DECADE of PROGRESS in **Industrial Phototubes and Photocells** — By L. R. Koller — 51

EDITORIAL COMMENT — 1

INSTRUMENTATION FORUM — 54

MANUFACTURERS' NEW LITERATURE — Insert

ADVERTISERS' INDEX (for Part One) — Insert

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M. F. BEHAR Editor

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INSTRUMENTS The Magazine of MEASUREMENT and CONTROL

M. F. BEHAR
EDITOR

IN THIS ISSUE

Perhaps it should have read "Not In This Issue" referring to regular features crowded out. To the old subscribers whose habituated appetite will miss these bread and porridge rations, we whisper a discreet apology while escorting them to a Lucullan feast of a dozen succulent courses: the next fifty two pages; and to a new feature which, being on this page and hence not part of the banquet, is exactly and rigorously defined as *hors d'oeuvre*. It is a new "column":

THIS MONTH'S AUTHORS

represent a geographical, industrial and professional cross-section of instrument minded America: from Long Island to the Golden Gate; from petroleum to metals; from research to production. There being so many, your convenience will best be served by introducing them in alphabetical order and printing them subjects metallic.

BARRETT was born in South Dakota and reversed Greeley's advice: took his Ph.D. at Chicago in 1928, served four years as Physicist with the Naval Research Laboratory and for six years has been making Carnegie Tech's name signify outstanding work in *X-ray* and gamma ray research and application.

BATCHER was one of the earliest radio amateurs (1908) and operated Station 9YI in 1915-16 at Iowa State where he took his E.E. in 1920 after having served as radio instructor during the war. Since then his achievements in *cathode-ray oscillographs* and electronic applications have advanced these fields.

BEHAR, your editor, as pathetically trying to learn something about instruments, having designed and built his first one only a short *time* (33 years) ago.

CARSON took his M.E. at Purdue, was for five years a Westinghouse instrument designer; then associate editor of two industrial magazines in succession and now manufactures precision springs and spring-testing equipment with the aid of *machine shop instrumentation*.

CHURCHILL took his B.S. in 1915 and his C.E. in 1922 (interval, war service as Captain of Engineers in the 37th Div.) at Ohio, where he has been teaching since 1922. Between the Armistice and 1921 he did three years of civil engineering work. He is the author of "Physical Testing of Metals" published by the A.S.T.

EXLINE took his B.S. at Mt. Union in 1927 and his M.S. at Penn in 1932. From 1927 to 1932 was Industrial Fellow at Mellon Institute (physical research and instrumentation; for Koppers). Joined Gulf Research in 1933 and has been developing and testing oil-field instruments such as the Pyott-Ruder bottom-hole *pressure* gage.

JENKS came to Westinghouse from Purdue in 1915. After a four year company course, with night school on the side, he designed and installed recording blooming mill main drives. Since 1931 he has specialized in *electron tube* control.

KOLLER took his A.B. in 1917, and his Ph.D. in 1921 (interval, radio laboratory work with the Army Signal Corps) at Cornell, and has been with G-E since 1922, four years in the lamp works, and since 1926 in the Research Lab where his work includes *photocells and photocells*.

LINCOLN. Among his achievements in thirty years of *electrical* engineering are designing, constructing and operating one of this country's largest electrical testing and research laboratories, and writing half a dozen outstanding books on electrical subjects. Despite his job of national importance, he took his assignment so seriously that before writing a single line he went through all 120 issues.

MASTIN took his B.S. at Minnesota, U's School of Chemistry in 1913, worked in a beet sugar factory, and then as a research chemist in the Department of Agriculture for four years. Two years in the army (18 months in France) followed by 2 years in Porto Rico and 3½ years as chief chemist at a Beech-Nut plant. Came to California in '24 and joined Std. Oil Chem. (now Westvaco Chem. Co.) where for 7 years he did *weighing and proportioning* equipment installed under his direction.

PIGOTT is no doubt known to all readers, not only as Vice Pres. ASME and because his name has been synonymous with *Hand meter* research for 21 years, but for his design and installation of several large power plant, and for numerous patents on gages, meters, burners, valves and instrument. Since 1928 he has been in charge of engineering research for Gulf Research.

SCHROEDER had his B.S. in Chem. at CCNY and has specialized in coal-tar and petroleum, then spent a number of years in the apparatus industry. He wrote a number of articles on laboratory *instruments and apparatus*, some of which old subscribers will remember. He is now research chemist with a large petroleum company.

WEBB was born in Illinois in 1891, and obtained mechanical experience in his father's motor boat and engine shop. At thirteen he designed and built a model airplane that rose from the ground and flew under its own power. Then came the 1910 Sept. 23 adventure in Interstate Steel Transit World by way of Hannibal, Illinois. Graduating in B.S. in M.E. in 1914 since when he has been with Carbide for the last five years in charge and sole of *temperature and humidity measurement and control* and of all instruments

A DECADE OF PROGRESS

IT takes moral courage for the staff of a magazine to refrain from making its Tenth Anniversary an occasion for horn-blowing. It is a fact, however, that since *Instruments'* first issue came out ten years ago there have been tremendous advances in the fields to which it is devoted:

in the useful *applications* of instruments, meters, automatic controllers, inspection and testing devices, etc., throughout industry;

in their diversification, standardization and quality;

in the formulation of the theories underlying proper selection and correct application of these products;

in the recognition of Instrumentation as a distinct branch of engineering and as a distinct field of scientific management" even by some groups formerly antagonistic in the past (but now climbing on the bandwagon);

in the publication of *authoritative* texts on the several distinct branches of Instrumentation;

in the organization and management of *instrument departments*;

in the *training* of instrument apprentices, instrument engineers, etc.;

in the *influence* and *standing* of instrument men;

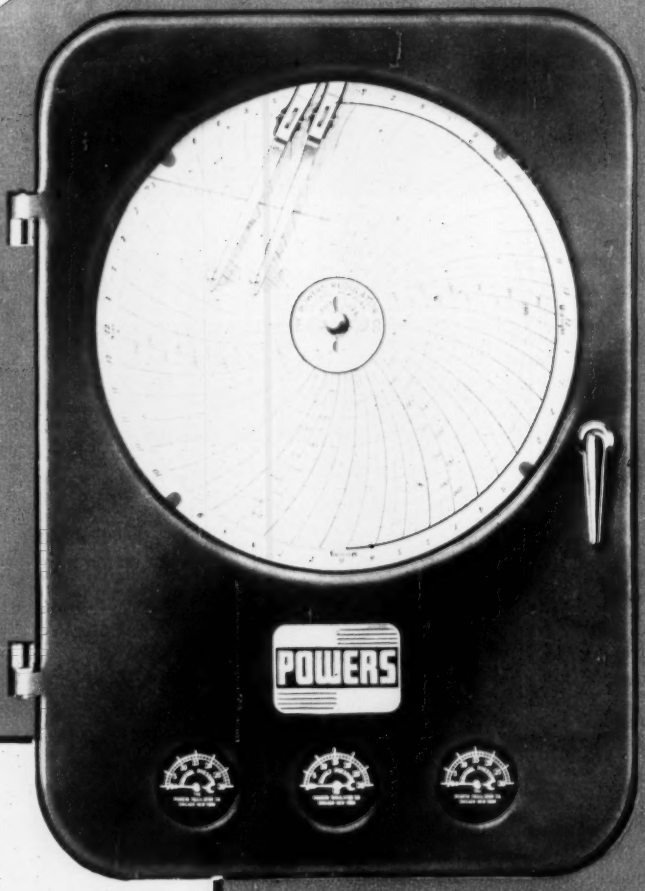
in the *economic status* of all instrument men, from young instrument apprentices to instrument minded high executives whose titles do not include the word "instrument";

and in the manifold blessings to civilization thereby brought about.

The editor takes this opportunity to declare that the moving spirit has been the founder and president of the Instruments Publishing Company, **RICHARD RIMBACH** (who will not see these secretly-inserted lines till they are in print!).

POWERS

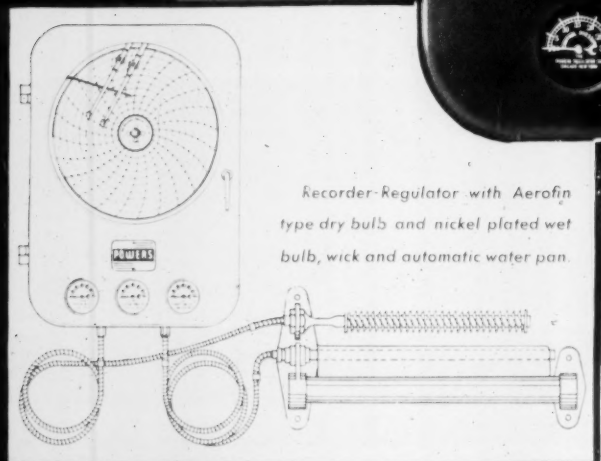
AIR Operated Controls



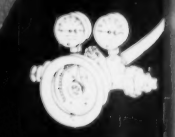
POWERS 2-PEN RECORDER-REGULATOR

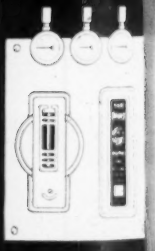
May be used to record and control two dry bulb temperatures; or, in combination with a water pan and saturated wick, both dry and wet bulb temperatures.

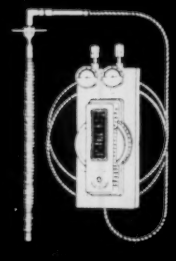
Write for Bulletin No. 226

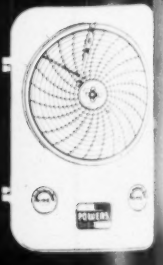


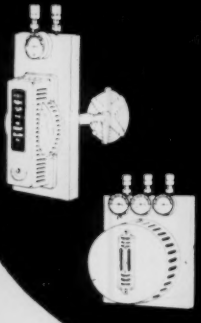
Recorder-Regulator with Aerofin type dry bulb and nickel plated wet bulb, wick and automatic water pan.

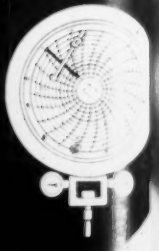












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POWERS

45 YEARS OF TEMPERATURE AND HUMIDITY CONTROL

A DECADE of PROGRESS in Temperature and Humidity Measurement and Control

By RALPH D. WEBB
Carbide and Carbon Chemicals Corp., Charleston, West Virginia

GO back ten years in industrial thermometry and especially in industrial temperature control, and you find yourself almost in the dark ages of these arts. Many industries still used old etched stem thermometers taped to pipe lines; those sporting recording thermometers with capillary tubes exposed to the hazards of outdoors were mystified every time a shower—or even a summer cloud's shadow—caused what we all know today as the tube error; temperature control was something that could only be applied to smaller units. Yes, good records were sometimes made, but usually if you pried the pen-arm loose from the chart so that it was more or less free to swing, you found that temperatures were not quite so steady after all. The old mushroom top type of diaphragm-motor valve was an endless source of irritation with its leaky stuffing box, crazy operating characteristics and an exasperating habit of opening wide when the air pressure failed—a not too infrequent occurrence. Today things are different, for tremendous advances have been made in all ramifications of this work. The following briefly covers some of these.

I—TEMPERATURE MEASUREMENT

Passing by the etched-stem, or laboratory type of glass thermometer, with due cognizance of its permanent importance, industrial thermometers give evidence of progress made these last ten years, although at the beginning of this decade these instruments were well developed and offered an acceptable accuracy at relatively low cost. The outstanding advances made have had to do with readability:

The Palmer Co. developed a "red-reading-mercury" thermometer, employing the flat front of the mercury thread as a mirror to reflect a red column to the observer's eye, no mercury being directly visible. Other companies brought out various color-contrast mercurial thermometers with lens-front tubing. "Binoc" tubing, introduced by Taylor, further departed from the old cylindrical glass stem by using a unique triple-lens construction, giving a wide-angle reading (readability with both eyes) and better illumination of the mercury thread. The scientific use of color schemes on the etched metal scales has further improved ease and accuracy of reading. Navy influence is shown in the plastic cases on small "Submarine Type" units.

The bi-metallic type was improved by several companies. Weston, for example, after several decades of specializing in electrical indicating instruments, suddenly came out with a scientifically designed "coils within coils" form of bi-metallic element and within the last few months have begun to produce industrial models. The manufacturers who supply bi-metallic elements to instrument-makers carried on some important research projects and as a result these elements are of a much higher grade than they were ten years ago.

The rigid-stem form dial thermometer which Consolidated Asheroft Hancock introduced under the name "Any Angle Thermometer" represents a big improvement in dial thermometers. By hinging the case to the stem and using two turns of small stainless steel thermal system capillary about the hinge, a really "Any Angle" thermometer has been made. Further flexibility is achieved by rotating the dial 90° or 180° in the case and resetting the pointer.

Dial type thermometers employing pressure spring thermal systems are so closely related to the recording thermometers of this class that it is unnecessary to make a separate listing of their improvements these being reported in the following paragraphs on recorders:

Pressure spring recording thermometers made great strides since 1928, as practically every part, from socket to case, has made its contribution. Alloy steels, particularly 18-8 chrome-nickel steel, are being extensively used for sockets, partly because of their corrosion resistance, partly because of strength, but mainly for an apparently paradoxical reason—poor heat transmission. The heat transmission capacity of these steels is only about one twenty-sixth of that of copper, and this property definitely reduces the conduction losses from that portion of the socket enclosing the sensitive portion of the bulb to the end of the socket which is subject to ambient temperature effects. The strength of steel permits thin walls with safety, thereby partly neutralizing the poorer heat transfer to the bulb. The "Thermospeed" construction offered by Taylor is claimed to still further improve the trueness of the bulb temperature by giving much more metal-to-metal contact between the bulb and socket. A small half-sleeve made of thin corrugated aluminum is forced into the annular space between the bulb and the socket, giving six or eight full-length contacts.

Liquid filled thermal systems came into their own this decade as capillary compensation was virtually perfected. The small bulb, inherent with this type, is a beautiful solution to the problem of proper bulb immersion, but previously this same smallness limited the capillary lengths because of the volume ratio of capillary to bulb.

By paralleling the capillary for its full length with another identical capillary, and by connecting each capillary to like pressure springs, which in turn drive the recorder pen through differential linkage, an accurate compensation for capillary and "head" or case temperature errors is achieved. The Foxboro "Anti-Ambi" thermometer is built on this principle and has proved quite practical from minus 185° F. up to 500° F., using capillary tubing lengths of 150 feet and greater. Bristol also produces this type of thermometer.

Bristol introduced a compensated gas-filled thermal system, known as the "Small Bulb," which uses the second gas-filled capillary and spring, connected to the pen arm through "whiffle tree" linkage to compensate for case and tubing temperature errors. Bulb sizes are reduced to approximately one-half those used in single-capillary thermometers while still retaining equivalent accuracy, although the compensation is not exactly true because of the difference in pressures in the paralleling systems.

A thermal system is manufactured by Tagliabue in which an all-stainless-steel mercury filled system is compensated for ambient effects by using a gas filled capillary alongside of the primary capillary. The gas filled tube is connected to a capsule which positions the mercury filled pressure-spring in the recorder case.

An outstanding advance in the field of compensation of mercury pressure-spring thermal systems was the Taylor "Accuratus Tubing": a steel capillary tube with an extremely accurately drawn bore having an Invar wire inserted therein. The expansion coefficients of the two unlike metals are such that the annular space between them varies in volume exactly as does mercury. This system leaves the pressure in the pressure spring unaffected by temperature changes along the capillary, minimizing the possibility of its being over-ranged by excessive temperatures along the capillary.

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FRIEZ of BALTIMORE

The vapor pressure type of thermometer has been improved by refinement of construction. Mason-Neilan claim to have overcome one of the big bugaboos of this type by offering an over range protector, a much-needed feature.

Their system has a bellows, located in the recorder case, which is normally retained at a constant volume but which is permitted to expand should the system pressure become excessive, even to the point of drawing all liquid from the bulb, thus protecting the whole system from further rise in pressure. When the bulb temperature returns to a safe point, the bellows is forced back to its original volume and the liquid returns to the bulb. This class of thermometer is now usable for temperatures near and below atmospheric as it can be made with the pressure-spring and capillary filled with a liquid of high boiling point, while the bulb only is filled with a lower-boiling point liquid. This prevents the "kick" which is so noticeable in the conventionally filled system as the bulb temperature drops below that of the capillary and spring, causing the filling liquid to "flash."

The general adoption of more flexible pen arms, giving a lighter "touch" to the pens, has greatly improved the sensitivity of practically all makes. Lighter linkage also has helped in this respect. A refinement in linkage angularity is noted, several companies adhering strictly to rectilinear arrangements. This and the use of better printed charts on more uniform paper have made for higher accuracy of recorded measurements.

Greater durability and greater permanent accuracy have been built into most thermometers on the market today by a fairly general adoption of atomic welding of steel systems, brazing instead of soft soldering joints of copper, brass and bronze systems, improved heat treating and seasoning of pressure springs, and finally, the use of stainless steel for capillary armor.

With the recognition of the need for more accurate temperature recording in industry, the electrical resistance thermometer is being more generally used, especially in the low and medium-temperature ranges. Perhaps the improvement in the recorders themselves is responsible, but with the lower-cost nickel wire bulb and the null type recorder, with its non sparking synchronous motor drive, this type of thermometer is moving forward rapidly. At least six major companies now offer this type bulb and recorder, whereas ten years ago only one offered the null type recorder, and their recorder had a sparking governor on the motor.

The pyrometer group has been improved in the same order as has the electrical resistance type. Greater standardization of thermocouples and of lead wire, achieved through technological improvements in their manufacture, has likewise improved accuracy and has made it possible to replace primary elements or thermocouples at any time without reference to individual calibration charts. The use of the air cell type of battery in place of the dry cell has materially reduced the need of daily standardization of those recorders not incorporating automatic standardization.

This type of temperature measurement instrument has made the tremendous forward step of incorporating electron tubes into the recording mechanism. As used in the Leeds & Northrup "Speedomax", the use of electron tubes gives a mechanism that travels the whole range of the chart in what had been considered an incredibly short period of time. Tagliabue brought out a self balancing system using the photoelectric cell, in conjunction with a light beam reflected from a mirror directly mounted on the galvanometer coil, to control the recording mechanism of their potentiometer. Other companies are showing a definite trend toward the use of the electron tube which is, in fact, a virtually instantaneously operating and frictionless "valve" or "switch."

Optical and radiation pyrometers have made their biggest strides this last decade through the use of the electron tube. Temperature measurement to within 5 F. in the 2,000 F. and the 3,000 F. range is being achieved by radiation pyrometers and is proving quite satisfactory because of its low lag characteristic.

II—TEMPERATURE CONTROL

A revolution has taken place in temperature control in industry since the first issue of *Instruments* appeared. Starting with refinements for those processes satisfactorily using the off-and-on mode of control, it has been changed and developed until now great units such as our oil cracking still furnaces, with their tremendous lag characteristics, are being controlled to ±0.5 F. in the 1,000 F. range.

Self operating controllers have been developed to control satisfactorily in the atmospheric range and when used in the higher ranges, can now be obtained with reasonably small bulbs, stainless steel capillary, and valve trim that needs no attention for many months at a stretch.

The off and on controller which, as claimed by one company, is suitable to 65% of temperature control applications, has been improved in many ways. The improvement of the temperature measuring elements probably constitutes the greatest step, but we see many diverse methods now available for operating the valve without retarding the indicating or recording mechanisms much, if any. Those instruments employing compressed air power devices generally embody the light flapper and nozzle system. Those using electrical operation in conjunction with pressure spring thermal systems achieve this low "detent" or retarding effect by positioning fingers, as is done by Brown and by Taylor, to move mercury bottle switches, or through the use of a low friction commutator type of switch such as Foxboro's "Rotax." In the pyrometer field, particularly with the galvanometer type of indicator, we find again the electron tube—this time acting as an oscillator tube so that the pointer merely has to carry a light metallic vane between two oscillating "pancake" coils. In the semi potentiometer type of indicator controller, we find Tagliabue using photoelectric cells which are actuated by the light beam pointer.

Pioneered by Foxboro with their Stabilog, which was introduced in the early 1930's, we now find many companies producing air-operated temperature recorder controllers incorporating adjustable throttling ranges and adjustable automatic resets. While both of these characteristics were known in other fields of control under other names, it is not until this decade that we find them generally available in the temperature control field. No longer do we change, adjust, restrict, and bypass the controller and controlled valve as was necessary with the old off-and-on controller. Sockets for protection of the thermal system bulb are now permissible because response need not be lightning fast. Controlled valves may be deliberately installed oversize to take care of start up periods and emergencies, whereas ten years ago such a thing led to poor control or made control impossible.

Automatic reset has allowed the use of heretofore impossible throttling ranges made necessary by the tremendous lags inherent in some processes. It has refined control to the point where tremendous load changes can hardly be detected on the temperature record. In the air-operated field, two systems of automatic reset are used, the one used by Foxboro which is that of using opposing bellows connected to each other by a length of

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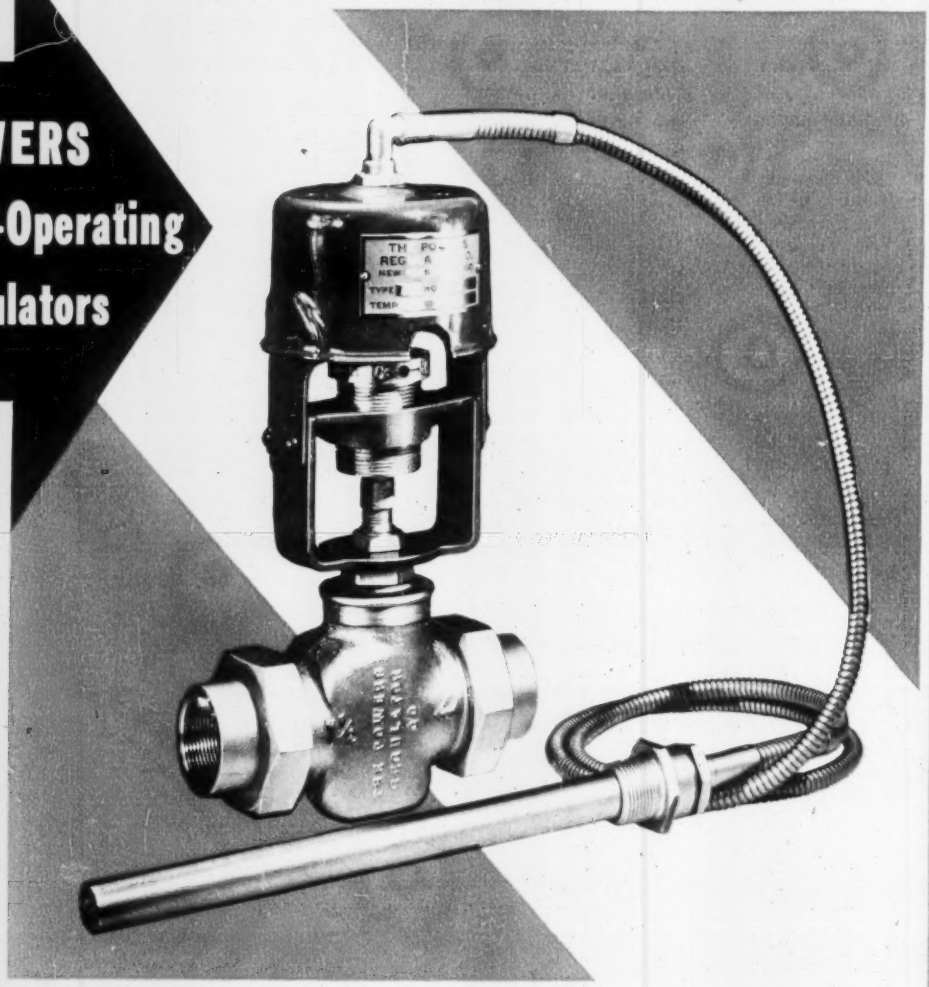

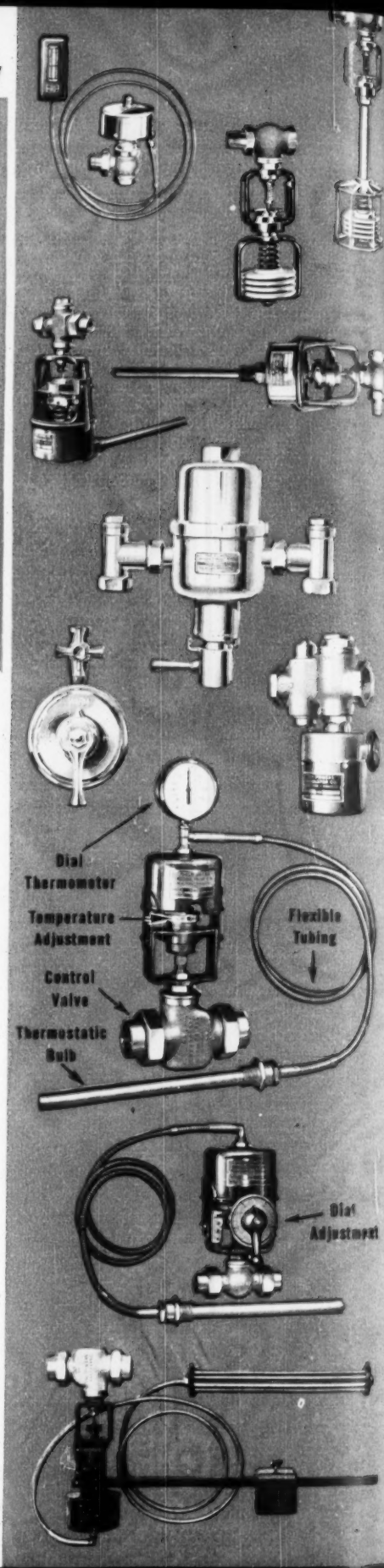

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small bore capillary tubing, and a system whereby opposing bellows or pressure elements are connected through an intermediate liquid-filled system serving the same purpose as the air-filled capillary to slowly drive the temperature back to the control point. While both systems are affected by temperature, that is, their reaction is slower when the mechanism is cold than when it is hot, the liquid-filled system is distinctly more subject to this deviation.

Mechanisms that approximate the actions of a highly intelligent operator are made which can be incorporated into the types of controllers just mentioned. For instance, the little capacity tank in Foxboro's Temperature Stabilog tends to cause the controlled valve to be moved too far whenever a temperature change occurs, but in a short period this extra bit of movement is taken off and the controller then slowly drives the temperature back to the desired point, the effect of the over control being that of putting in or taking out an extra amount of the fluid under control to compensate for the time lost between that moment when the temperature actually changed in the unit and when the temperature change reached the primary element of the temperature controller. Taylor's "Preact" has this same general effect. Additional instruments, like Foxboro's "Impulsator," are used to add or subtract increments of the controlled fluid depending upon the trend of the temperature rather than on the fact that it had just departed from the control point.

The controlled valve has had much to do with the development of temperature control these last few years. Diaphragm motors of power and low hysteresis have been developed. More important, though, are the characteristics which have been built into the inner valve construction. The wide-range type of valve, which gives approximately a constant percent in change of flow for any given increment of valve lift, has materially aided temperature control. It is now possible to adjust the controller throttling range so that the unit being controlled neither drifts about nor over-controls when the valve load changes—an almost impossible achievement with the older style inner valves.

Possibly the finishing touch to the air-operated temperature controller has been the valve positioner. This instrument—and it must be an instrument if it would give proper control—absolutely makes the valve assume proper position for any pressure which might come from the controller proper. This removes the last dead spot in our control mechanism. Taylor probably deserves credit for first introducing this mechanism, as incorporated in their "Dubl-Response" unit, and later in their "Valv-Precisor." Other companies, Foxboro, Brown, Bailey, and Mason-Neilan, have placed on the market this general type of mechanism.

Controller systems using a combination of the potentiometer type of electrical measurement and the pneumatic power device have been made available by several companies. The Foxboro Potentiometer Stabilog, incorporating the Stabilog control mechanism and a semi-potentiometer temperature indicator, was the first commercial instrument of this type on the market although Luis de Florez developed such a controller previous to this. The Foxboro instrument uses the chopper bar principle to position the flapper of the air controller mechanism and, while the galvanometer deflection governs the position of the flapper, there is no dead spot in this particular mechanism. Brown, Taylor, and Mason-Neilan all offer controllers in which air mechanisms have been added to regular null type recording potentiometers. In these cases the position of the slide wire governs the position of the air flapper, consequently no flapper movement can be made which is less than the distance between two turns of the slide wire.

The all-electric type of control system has been changed from the old two-position or three-position controller until now it has many of the desirable characteristics of the air-operated control system. Valve movement has been made proportional to the departure from the control point, and automatic reset can be had, although it is usually in the nature of a periodic "kick" used to drive the temperature back to the desired point. Electrical power devices, however, are almost universally used in conjunction with instruments having radiation pyrometer primary elements, an exception being the control system made by American Askania, which employs a hydraulic system of throttling control.

III—HUMIDITY MEASUREMENT

Although most of the numerous principles that can be employed for humidity measurement had been thoroughly investigated before 1928, the great majority of industrial instruments utilized principles subject to considerable errors. In fact, it seems pretty safe to assert that all of the "industrial" instruments manufactured in mass-production lots were simple hygroscopic indicators and unventilated wet and dry bulb units—both types unsuitable for the majority of important industrial applications. The American instrument industry could not undertake to produce accurate and relatively expensive instruments such as the Assmann psychrometer (to cite one example) for which there was practically no demand even from textile mills, printers and other industries that had recently become "air-conditioning conscious." Today we find portable aspiration psychrometers made by several American instrument companies—in forms that are improvements over the original (German) Assmann laboratory design—and being purchased in large numbers although they naturally cost around fifty times as much as simple hygroscopes.

This is but one example of an educated taste recently acquired by industry. Here, too, as in the field of temperature measurement and control, credit for educating us industrial users should go to *Instruments*. A series of articles was published in *Instruments* during 1930 (chapters of Behar's Manual of Instrumentation) which constituted the first handbook on industrial humidity measurements. About sixty pages of this serial were devoted to analyzing all the principles and all the types of instruments. Demand for modern humidity instrumentation on a par with temperature, flow and pressure instrumentation was stimulated. In addition to precision indicators, highly developed recorders were called for, in self contained and long-distance models. Some instrument companies were prepared to meet this demand with little delay, having begun to do research and development work on such recorders in the twenties. They rapidly went into production. Others followed suit. An excellent result of it all, as far as the user is concerned, is that competition between the hygroscopic material and the wet-and-dry classes—and between various types within these classes—has led to big improvements in each class and type.

Much progress has recently been made also in "aerological" instruments—those pertaining not only to humidity but to air circulation, radiation, air purity, etc. While the keenest demand has come from hospitals and other institutions, enlightened industrial management has eagerly used such instruments, as aids to improving working conditions as well as for increasing the efficiency of processing foods and numerous other products.

IV—HUMIDITY CONTROL

Industrial humidity control systems available ten years ago employed better measuring elements than did most humidity indicators and recorders on the market. The reason no doubt was that the price difference between a highly perfected atomizing psychrometric element (for example) and a cheap bottle-and-wick affair, represented a small fraction of the total installation cost.

Every reader knows, of course, that during the last decade more striking progress has been made in the general air conditioning field than in purely industrial humidity control. However, this is only relative. If we could overlook the sensational growth of domestic, theater and institutional air conditioning instrumentation we would be impressed by the tremendous advances made in the automatic control of humidity in kilns, dryers, and other closed apparatus as well as in spinning rooms and numerous other purely industrial applications. As a matter of fact, these two broad fields have advanced side by side and to a large extent have been served by the same companies. Most of the companies mentioned above in connection with temperature control have brought out improved humidity control systems. Some of them had for years worked in conjunction with domestic air conditioning firms. In addition, improved systems were brought out by the companies which limit their work almost entirely to air conditioning. Carrier has mostly stuck to ventilated wet-and-dry-bulb elements; Parks Cramer brought out an atomizing type and also a hygroscopic type employing human hair. This type has for many years been favored by Friez and that company brought out in recent years a remarkably large number of different models of humidistats employing various arrangements of processed human hairs. Other hygroscopic materials, however, have been favored by other companies: a 21″ fibrous ribbon by Lewis; a cylinder of applewood (among other types) by Johnson Service; an animal-membrane strip by American Moistening.

Pneumatic, hydraulic and electrical power devices are used to operate the valves of heating, cooling and humidifying media; sometimes two forms of power in one control system. Heating and cooling medium valves are usually throttled; spray valves are usually required to be open or shut. In most respects, however, advances in humidity control power devices have followed those in temperature control—followed somewhat behind.

A DECADE *of* PROGRESS *in* High Temperature Research

Contributions of the National Bureau of Standards

By M. F. BEHAR

DURING the past ten years, the principal development, resulting largely from the work of the National Bureau of Standards, has been the use of freezing metals as standards for the quantitative evaluation of radiant energy.

When Waidner & Burgess[1] suggested, in 1908, that the ideal standard of light would be a hollow enclosure (or black body) immersed in a bath of freezing platinum, it was probably without any idea that it would be realized in practice. The principal difficulty was a refractory material from which to make the enclosure and a crucible to hold the liquid platinum without contamination. Graphite is a useful refractory: it does not melt below about 3700° C. (6700° F.), a temperature at which every other known material is either a liquid or a gas, and it has an almost unlimited resistance to thermal shock. It can be used with gold, melting point 1063° C. (1945° F.), but it is soluble in practically every molten metal whose melting point is above that of copper, 1083° C. (1982° F.).

In 1929 Fairchild, Hoover, and Peters[2] operated a black body immersed in freezing palladium in determining its melting point (or freezing point) to be 1554° C. (2829° F.). They used crucibles and black bodies of "Sillimanite" porcelain, which were found to have a short life at this temperature. Between the time that this work was completed in 1923 and its publication in 1929 Bowen & Greig[3] found that silica and alumina, the constituents of sillimanite, form a eutectic which melts about 10° C. below the melting point of palladium. For higher temperatures, therefore, no suitable refractory was available.

In 1925 Fairchild & Peters[4] succeeded in fusing thorium oxide, in an electric arc between graphite electrodes. Conversion of the thorium oxide to thorium carbide was inhibited by using hollow electrodes through which a stream of pure oxygen was fed into the arc. Fused thorium oxide proved to be the long-sought refractory which made possible the carrying out of the suggestion of Waidner & Burgess. In 1931[5] their standard of light was shown to be accurately reproducible and entirely practical. By international agreement effective Jan. 1, 1940, the unit of light intensity, the "new candle" (to distinguish it from the old units which did not have exactly the same value in any two countries) becomes simply 1/60 of the intensity of 1 cm² of the Waidner-Burgess Standard.

Another Bureau accomplishment was the operation of a black body of thorium oxide in freezing iridium. At the platinum point 1774° C. (3225° F.) a black body emits light of the color of the old carbon standards. The fundamental unit of light is thus maintained in terms of a candle of the same quality (color) as before. Practically all lamps sold, however, are gas-filled tungsten lamps, having a color nearly that of a black body at the iridium point 2454° C. (4449° F.) The comparison of carbon lamps with tungsten lamps has been attended with such uncertainty, due to the color difference, that the same tungsten lamp would be given ratings differing by as much as 5% in different countries. By comparing a tungsten lamp with the black body in freezing iridium and a carbon lamp with the black body in freezing platinum, the relative values for the two lamps can be determined[6] without ever matching a light of one color directly with one of another color. The comparison can be made by this method, more accurately than by any other.

Black bodies immersed in freezing platinum (1774° C.), rhodium (1966° C.) and iridium (2454° C.) were also used to establish[7] a fundamental scale of color temperature. The color temperature of a body is a specification of its color in terms of the temperature at which a black body or uniformly heated hollow enclosure will attain the same color.[8] If a tungsten filament electric lamp is operated at a series of voltages, it will take on the series of colors of a black body at various temperatures and forms a convenient working standard.[9] To determine the relation between the voltage and color temperature of a lamp, characteristic of that lamp only, it obviously is necessary to have a black body at the required temperature to make the comparison. In the past this has been done only at lower temperatures, the higher values being obtained by more or less uncertain methods of extrapolation. The black body immersed in freezing metals has given us a scale with an absolute accuracy of 3° C. up to about 2150° C. Extrapolation above this point becomes much less uncertain in the light of reliable data on the relation below this point.

The possibilities of the black body immersed in freezing metal as a tool for the quantitative evaluation of radiant energy are by no means exhausted. Its use as a standard for work in the ultraviolet is one of a number of developments which can be confidently expected in the next decade.

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[1] *Electrical World*, Vol. 52, 1908, page 625.

[2] *Bureau of Standards Journal of Research*, Vol. 2, 1929, pages 931-943.

[3] *Journal American Ceramic Society*, Vol. 7, 1924, page 238.

[4] U. S. Patent No. 1545954.

[5] Wensel, Roeser, Barbrow & Caldwell, *Bureau of Standards Journal of Research*, Vol. 6, 1931, pages 1103-1117. (R.P. No. 325)

[6] Derivation of Photometric Standards for Tungsten-Filament Lamps, Wensel, Roeser, Barbrow & Caldwell. *Bureau of Standards Journal of Research*, Vol. 13, 1934, pages 161-168. (R.P. No. 698)

[7] Wensel, Judd & Roeser, *Bureau of Standards Journal of Research*, Vol. 12, 1934, pages 527-536. (R.P. 677)

[8] At room temperature the color of a small opening in such an enclosure is black, approaching perfect blackness (absorption of all light falling on it) as the size of the opening is diminished. This explains why the term black body is applied to a device which takes on a series of colors as its temperature is changed. Obviously only a certain range of colors, represented by a line on any color diagram, can be matched with those of black bodies. Most sources of illumination, however, lie on or near the so-called "black body locus."

[9] Tungsten lamps with a certificate giving corresponding values of voltage and color temperature are distributed by the National Bureau of Standards.

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A completely re-designed line, including several new types of exhaust pyrometers, single, multi-point and portable for all sizes of Diesel and Gas engines as well as several styles of mounted and portable types for general service are also a development of the last decade.

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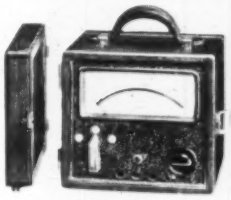

Type 2900 Portable
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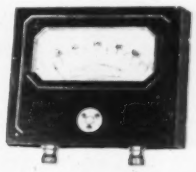

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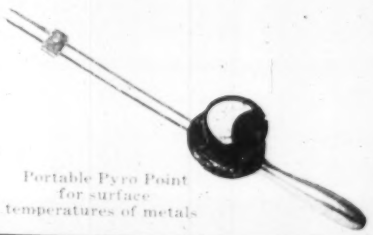

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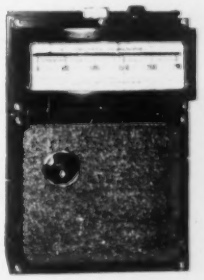

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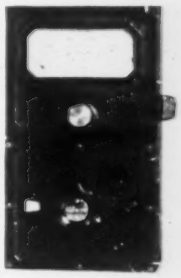

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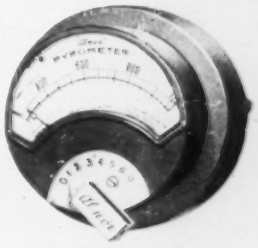

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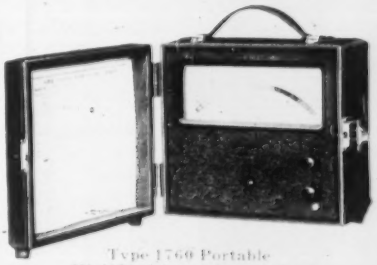


Type 1760 Portable
High Resistance Pyrometer

A DECADE of PROGRESS in

Pressure and Vacuum Instrumentation

By PAUL G. EXLINE

Engineer, Gulf Research & Development Corp., Harmarville, Pa.

IN an effort to present as much material as possible, this review consists of a series of thumb-nail descriptions. The field is too vast[1-4] for an exhaustive review in the allotted space, but every effort was made to make the list representative.

I PRESSURE MEASUREMENT

1. PISTON GAGES

A properly constructed piston gage provides the best known method of measuring pressures accurately over a wide range. For precision work, the radial clearance will lie somewhere between 0.000,04″ and 0.0002″. The effective area being close to the mean of the areas of the piston and cylinders, both diameters must be accurately known. It is customary to make the diameter such that when weights which are integral multiples of 1 lb. are placed on the pan, the developed pressure will be in integral multiples of 1 lb. in.$^{-2}$.

Expense of precision manufacture, and inconvenience in measuring pressures, generally restrict the use of this type gage to calibrating other gages.

Consolidated Ashcroft Hancock brought out gage testers in which the piston gage and pump are mounted on a rigid cast iron base, with a convenient mounting for the gage under calibration. Accuracies of 0.1% may be obtained.

A series of piston gages was brought out by the American Instrument Co. in ranges up to 50,000 lbs. in.$^{-2}$. The weights, instead of being placed on top of the piston, are suspended below it by means of a yoke. This prevents injuring the piston when many weights are used. A motor oscillates the piston so that correct pressures may be obtained. Accessories: a hand pump which develops 15,000 lbs. in.$^{-2}$ and (for highest pressures) a 10:1 ratio intensifier.

A spring-loaded piston recording gage is made by Esterline Angus in ranges up to 5000 lbs. in.$^{-2}$. In such a gage, piston travel from zero position is a linear function of applied pressure.

Bailey Meter Co.'s ingenious application of the piston gage to a power-operated pressure device permits long-distance telemetering. The system operates as follows:

The transmitter (illustrated) has a pressure connection at the bottom of the cylinder in which floats a small pressure piston supporting a pilot valve and a cup containing mercury. The piston is continually rotated in order to eliminate the effects of friction. The same motor which drives the rotating worm also operates a gear pump which supplies oil to the pilot valve under pressure. From the pilot valve, oil is carried through one of two ducts, depending upon pilot position, to a large-diameter power piston. When the applied pressure increases, the pressure piston rises and in so doing permits oil under pressure to pass through the pilot valve to the upper side of the power piston. This causes the power piston to move downward, forcing the displacer deeper into the mercury. The reaction of the buoyant force of the mercury against the displacer will cause the mercury cup and pilot valve to be forced downward against the increased pressure under the pressure piston. This downward movement of the mercury cup, pilot valve and pressure piston returns the pilot valve to its neutral position and closes off the oil supply to the power piston. Consequently, for each pressure applied to the small rotating pressure piston, a definite position of the power piston and displacer is obtained. A Selsyn transmitter is geared to a rack on the power piston rod so that its position is an accurate indication of the applied pressure. The receiving Selsyn indicators and recorders of course assume the corresponding position. By varying the diameter of the pressure piston, the size of the mercury cup and the size of the displacer, it is not only possible to furnish this power pressure unit for practically any maximum pressure but also for a large zero suppression. Indicators as large as 12″ in diameter have been made, with a total pressure range of only 30 lbs./in.^{2} for an average operating pressure of 100 lbs./in.^{2}

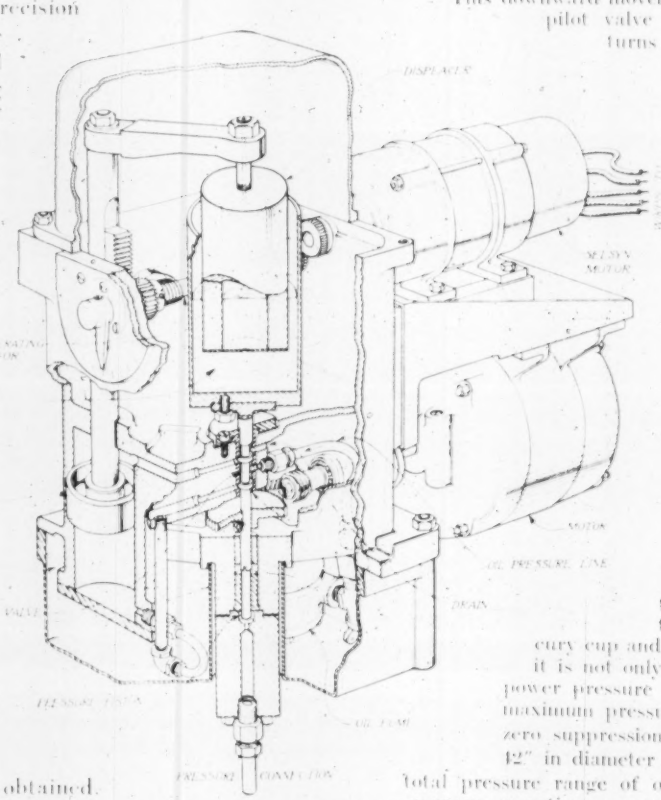


Fig. 1. Bailey piston type transmitter.

Bacharach brought out a spring-loaded differential type pressure recorder for rapidly fluctuating differential pressures. The piston and cylinders are lapped and, with equal pressures applied to each end of the piston, there is no displacement. A straight-line linkage device gives six times magnification to the stylus, tracing the record on the drum which can either be turned by the mechanism under test or by a clock. The zero line can be placed at any point on the chart. Practically any range desired can be obtained by means of interchangeable pistons and springs.

2. LIQUID GAGES

(a) Barometers

Ten years ago the standard mercurial barometer had reached virtual perfection—in its standard form. Variants of this form had to appear—and did. The recently announced Cenco Improved Mercurial Barometer

resembles the standard Weather Bureau type but differs principally in the design of the mercury cistern and the method of adjusting the mercury level.

The cistern consists of a heavy, clear glass cup flanged at the bottom for positive grip and threaded at the upper end for the vertical adjustment. The male threads on the glass engage threads on the Bakelite well mounting, which is cemented to the glass barometer tube and which carries the ivory index pointer. Adjustment is accomplished by screwing the cistern up or down until the index just touches the mercury surface. The cistern can be sealed for transportation by screwing it tightly against a gasket. The barometer tube has a 0.4" bore and is filled with exceptionally pure mercury. The brass case carries two scales, one graduated in English units and the other in metric units. The upper vernier has sighting points to eliminate parallax. The total range of 200 mm. can be read to 0.1 mm. or 0.005".

The Podbielniak recvacuable barometer is so named because it can be shipped empty and filled at the point of use with no special equipment. No adjustments or settings are necessary.

The case of the new Gaertner 50,000 ft. mercurial barometer (Fortin type, U. S. Army Air Corps specifications) is square, permitting the use of flat scales, which aids reading. One scale is graduated from —1,000 ft. to 5,000 ft. and the other reads from 85 mm. to 810 mm. Both scales are graduated to compensate for change in level in the cistern. In order to facilitate readings, the vernier divisions are 1.9 mm. apart rather than 0.9 mm.

(b) Micromanometers

Micromanometers had reached a high degree of perfection before 1928. Few new ones were brought out.

The Casella micromanometer consists essentially of a U tube, the liquid level of one leg being adjustable so as to secure a given level in the other. The level in the adjustable leg is observed by means of contact of a submerged pointer with the surface of the water; it is viewed from below the surface at an angle at which the surface acts as a totally reflecting mirror. The pointer and its reflected image are seen greatly magnified in the eyepiece and the correct setting is made when the two just contact. Ranges of 0 to 36" can be secured, measurable to 0.0004" water.

The Teltru micromanometer, with a total range of 0 to 5", reading directly to 0.001" water, likewise utilizes a null method: the reservoir is raised to bring the level to a zero mark placed on the lower part of the glass tube which is inclined at that point for maximum sensitivity. A uniform-pitch screw and divided circle indicate the height of the column which balances the pressure.

"At least ten times as sensitive as the Chattock and the Wahlen" was the late John L. Hodgson's report on the actual performance of the "Super Micromanometer" which he described in *Instruments* (April 1929, pages 125-128). The writer has not been able to ascertain whether Hodgson had his remarkable instrument produced in commercial quantity lots.

(c) Draft Gages—Visible Column

Dwyer Mfg., and Friez, both brought out inclined tube and vertical-tube gages formed by accurately drilling solid blocks of transparent Bakelite. In the Friez instrument, a highly polished graduated scale is located on the back of the block so that parallax errors can be eliminated by lining up the meniscus scale graduation and the image of the meniscus. Such gages are available in ranges up to 4" water.

(d) Draft Gages—Inverted Bell

A new tandem system of straight-line movement pointer draft gages for zoned air flow under large forced draft boilers was brought out by Ellison. Each element consists of a movable bell within a stationary bell sealed at the bottom in mineral oil. Pressure at the damper inlet is piped into the top of the stationary bell and the damper outlet pressure to the draft tube of the inner bell. Thus, the movable bell is actuated by the net or differential pressure. The resultant movement is transmitted to the indicating pointer by means of an extension plate on the bottom of the moving bell and supporting rods, outside of the fixed bell to the knife-edge bearing on the beam. All bells are served by a common oil pan provided with an oil filler in back of the gage trough which oil level may be seen on a marker. A tandem arrangement permits use of two pointers on the same scale.

(e) Flowmeter Manometers—Glass

Jensen Instrument's glass U tube, wall or panel type manometer has an adjustable scale printed on an endless strip which rolls over a pulley at each end of the case. By turning a knob, the zero may be set at any point of the manometer from the top to the bottom. It is made for working pressures of 150 lbs. in.^{2}.

A unique mercury-in-glass recording manometer developed by Trimount uses one leg as an indicator and the other as a recorder. The recording leg is in the path of a line source of light parallel to the tube, the mercury level in which partially masks a sensitized chart rotating behind the manometer. Special seals are provided to keep the tube clean. Fresh charts of photographic paper are mailed monthly to users.

Meriam developed an inverted type manometer which has the bend at the top instead of the bottom. This permits use of the liquid being metered as the gage liquid. In case the differential becomes too great, the liquid would merely flow through the manometer. An air connection is provided for pumping air into the upper part of the manometer for adjusting the liquid level in the low pressure leg.

Another unusual manometer developed by Meriam uses two fluids to indicate both differential and total pressure.

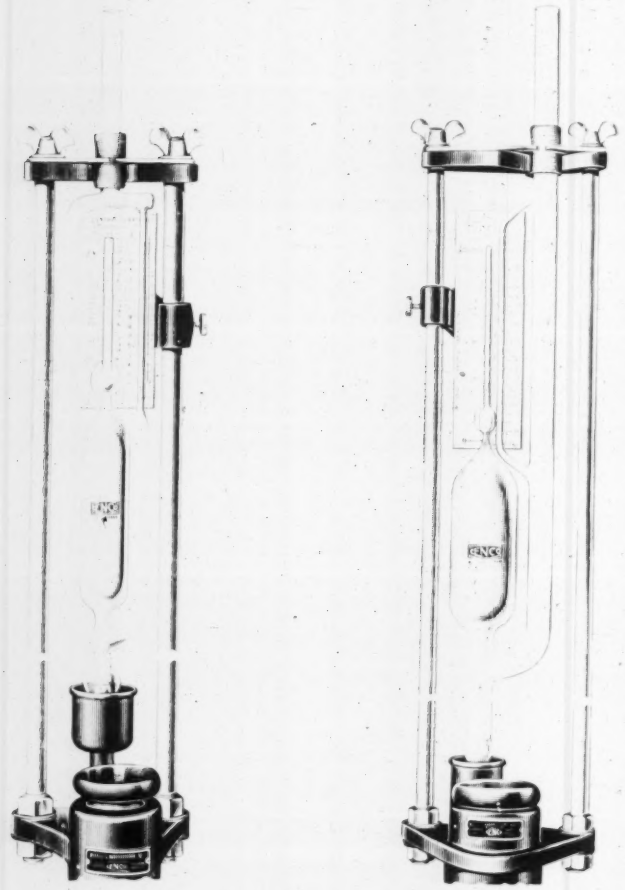
Still another Meriam flowmeter manometer has the head permanently connected to the line and removable from the housing which carries the scale, U tube, and brush for cleaning the U tube. Their high-range U tube manometer for differential pressure measurements has a steel frame, stainless steel packing gland followers, and a plate glass cover. These glass instruments are tested at 2500 lbs. in.^{2} and can be used at 1,000 lbs./in.^{2}. Mercury, water or "Meriam No. 3 fluid" (2.97 specific gravity) may be used. The standard scale is 35" long and when filled with "No. 3" will read to 100" water.

(f) Flowmeter Manometers—Mechanical and Electrical

The most important use of the U tube principle of differential-pressure measurement being for recording flow-rate, there was further progress in the development of flowmeter "bodies" or "secondary elements" during the last decade. Flowmeters as such are discussed in Pigott's review. We may record here the fact that improvements were made in all old makes of flowmeters *as differential pressure measuring devices*. In the new designs, too, special attention has obviously been given to minimizing sources of error in pressure measurement.

The first use of the null method applied to the automatic balancing of a mercury differential manometer was recently announced by Leeds & Northrup. (See Fig. 15 of Pigott's article.) Measurement of differential is accomplished by opposition of a mechanical force (fly-ball system) automatically varied to restore balance whenever the value of the differential changes. Electric motor power being ample, friction and other effects merely increase the load without introducing sources of error. Extensive tests have shown errors sufficiently small to enable the maker to guarantee a width of wedge of error of integration ±0.5% of actual flow at 100% flow and ±1% of actual flow at 25% flow, exclusive of primary element error (which when known can be compensated by adjustment of balance).

The null method is used also in the new Cochrane electric flowmeter (Fig. 16 of Pigott's article). The float riding on the mercury in one leg of a U tube carries a soft-iron armature which is the magnetic element of the transmitter of an induction-balance telemetering system. Balance is automatically restored by a galvanometer-commanded servo-motor in the receiver, so that the pressure-measuring float and its armature are at all times free from mechanical friction or electromag-



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netic drag. A displacement of the transmitter armature of less than 0.001" (corresponding ordinarily to 0.01% change in rate of flow at mid-scale) will cause the galvanometer boom to deflect and will result in a change in indication. Because no current flows through the galvanometer with the bridge in balance, the accuracy is unaffected by resistance of conductors, contact resistance, length of leads, distance between receiver and transmitter, etc.

(g) Electric Transmitting U-tube Manometers

The majority of these are for differential pressure, they are "flowmeter bodies." Some were brought out, however, for absolute pressure or gage pressure applications.

The Brown absolute pressure gage, for determining the back pressure against which a turbine is operated, is a slight modification of their older flowmeter body. It is a mercury filled U-tube type, one leg evacuated and the other containing a float carrying the magnetic element of the transmitting divided-solenoid of an induction balance telemetering system. The receiving indicator or recorder may be at practically any distance from the transmitting manometer. These systems are made for service within a minimum range of 0 to 100 mm. mercury absolute pressure.

In the mercury U-tube type pressure transmitter furnished by Bailey, the closed leg of the U-tube is connected to the source of pressure while the other leg terminates in an open reservoir in which a steel float rides on the surface of the mercury. As the displaced mercury rises in the open reservoir, the float in turn rotates the Selsyn generator rotor through a rack and pinion in direct proportion to the change in pressure.

3. ELASTIC-ELEMENT GAGES

(a) Slack diaphragm, Spring-loaded

Bailey developed a slack-diaphragm type multiple pointer gage employing a new diaphragm material resistant to oil, acid, caustic and heat and having exceptional flexibility with greater strength than gold beaters skin and the usual leathers. These gages feature a simple mechanical action in which the weight of the diaphragm is carried by the drive link, thus providing freedom of movement. The restoring force is supplied by a flat calibrated spring. Total effective diaphragm area is 20 in.^{2}. Zero adjustment is easily accessible through the case. Standard ranges are up to 6" of water. Suitable stops enable the gage to withstand an overdraft of 40" of water without injury to the diaphragm.

A line of indicating and recording draft gages using slack leather diaphragms suspended upon two needle point bearings is made by Defender. Convenient levers extend through the case for use in venting the gage and adjusting the zero setting. The cases are square, with one, two or three 12" vertical scales.

Republic's multiple draft and pressure indicator employs alum-tanned colon leather diaphragms, the center areas of which are held by pairs of aluminum disks each suspended in a vertical position by a long, two-point pivot bearing through which motion is transmitted to the pointer. Due to this suspension the diaphragm is not required to support any load.

A line of slack-leather-diaphragm draft and differential-pressure recorders is now made by Hays in 99 different ranges. The Series OH recorders contain large supersensitive elements in rectangular cases giving a scale range as low as 0 to 0.1" of water. The same slack leather diaphragm is used in the Hays portable draft gage. A convenient reel for rubber tubing is constructed in this instrument, which can be prepared for use in a sec., no leveling being required.

(b) Metallic Diaphragm

The Paulin System barometer is an excellent example of a precision metallic diaphragm instrument. It uses the null method: Changes in barometric pressure cause the pointer to deflect from its zero position, whereupon the diaphragm can be brought back to its initial position by turning the knob which both changes the tension of the loading spring and rotates the scale.

Two new drum-chart aneroid recording barometers embodying recent refinements in temperature compensation, seasoned seamless pressure chambers, jeweled 8-day clock and a fine-line pen were recently brought out by Friez. The "micro barograph" has six models, each with a range of $2\frac{1}{2}$" mercury over a $6\frac{1}{4}$" scale. The station barograph has a glass case, the $4\frac{1}{2}$" chart covering a range of 3" mercury.

The standard Brown line of 8" and 12" round-chart recorders utilize a flexible metal diaphragm for ranges from 10" water to 30 lbs. in.^{2}.

The pressure gages made by Fisher Governor utilize bronze diaphragm measuring elements for pressures below $1\frac{1}{2}$ lbs. in.^{2} (where U tubes are ordinarily used). Movement is of the "independent" type as specified for highest grade inspector's gages. The $2\frac{1}{2}$" diameter case is calibrated for ranges 0 to 35" water and 0 to 20 oz. in.^{2} with a guaranteed accuracy of $\frac{1}{8}$" water.

Rochester Mfg. Co.'s miniature diaphragm gages are designed for use in locations subject to intense vibration, and the diaphragms are backed up by plates which protect them against overloads several times the range of the gage.

(c) Bourdon tube gages

The Bourdon tube, one of the oldest forms of pressure gage elements, might be thought to offer little opportunity for improvement during the last ten of its eighty years' life which has seen its application extended to nearly every phase of pressure measurement. However, particular attention has been paid to the perfection of its form; realization of the dependence of its behavior upon the elastic properties of its material has resulted in the use of better alloys; its linkage has been improved and the external appearance dressed up.

The Duragauge introduced by Consolidated Ashcroft Hancock has a tube machined from a solid bar of alloy steel and a nitralloy steel movement. The pointer has an integral micro adjustment for zero adjustment and the uniform expansion of the tube permits use of a uniformly graduated dial. Gages in ranges up to 1000 lbs. in.^{2} are also furnished with molded plastic cases in order to reduce weight.

Crosby introduced an all-steel gage designed primarily for severe conditions of operation. The tubes are made from a solid bar of alloy steel, precision-turned and bored, then bent to shape. The ends are threaded and the end pieces screwed on. The sector and pinion are of forged steel with the teeth machined, hardened and chrome-plated. The bearings are of hardened stainless steel and the entire movement is carried by the socket rather than by the case.

Foxboro brought out a gage with a chrome molybdenum steel tube and hardened steel movement with cadmium-plated movement plates. They also supply a gage with the tube and all movable parts of heavily cadmium-plated bronze in which an Everdur hairspring is utilized. The dial is rotatable over a small angle for zero adjustment.

A high-precision gage, to be seen on numerous physical testing machines, is made by Heise Bourdon Tube Laboratories. Attention is paid throughout to perfection of workmanship and construction, in order to be able to offer an accuracy of 0.5% of actual indication above 20% of full-scale deflection. The gage is offered in 12" and 16" sizes only. A certified calibration can be supplied.

A Bourdon tube gage supplied by Marsh for dairy use utilizes a tin-tipped phosphor-bronze separatory diaphragm in an easily cleaned mounting. The pressure-transmitting liquid has a low freezing point and compressibility, making it suitable for low temperature uses.

A similar type gage is manufactured by Negretti & Zambra for aircraft applications where breakage of the Bourdon tube would cause a dangerous condition through loss of oil. The diaphragm in this case would act as a protective seal. A non-freezing liquid fills the capillary tube between the gage and the diaphragm case.

Two pressure elements have been combined by Taylor to form an unusual gage. An elastically deformable bulb is connected to the Bourdon tube in a standard recording gage case. The system is filled with mercury and is so compensated that temperature changes have no effect on the pressure indication. Deformation of the bulb walls due to pressure forces mercury into the Bourdon tube, thus causing it to deflect. This unique gage is designed for application in the high-pressure side of a homogenizer although there should be other applications for it.

An example of dressing up is shown by U. S. Gauge in their new square case gage in which modern ideas combine a pressure gage and thermometer in an attractive case.

A multi-contact making gage for use with supervisory control systems to indicate certain predetermined pressures at a remote point has been developed by Westinghouse. Ten adjustable contacts may be set at as many chosen points within the range of the instrument. When the pressure changes sufficiently to make a new contact, a characteristic code of impulses is sent over the supervisory control wires. The contact carried along by the pointer has no mechanical connection to the rest of the instrument.

(d) Bellows

An outstanding development during the past decade has been the perfection of the metallic bellows and its application as a pressure responsive element. Combining, as it does, characteristics which make it particularly adaptable to the measurement of pressure, it is not surprising that it has been tried by so many manufacturers. In spite of its rapid growth, the writer feels that this field has been but lightly touched and that the future will show this element encroaching upon the field now entirely occupied by the Bourdon tube. Little material has been published describing the behavior of metallic bellows although the experiments of the writer have shown linear response, high available energy, and suitability for use over a wide range of pressures to be characteristics easily obtainable. Of the commercial gages described below most are constructed for pressures below 200 lbs. in.^{2}.

At the present time one of the most serious drawbacks to the bellows is the necessity for the use of non-ferrous materials in its construction. Some attempts have been made to form bellows of alloy steel but the difficulties of the subsequent heat treatment, essential to the development of suitable elastic properties, have been too great. It is to be hoped that more attention will be drawn to this development in the near future and that heat treated alloy steel bellows will become commercially available.

(d 1) Absolute-pressure Bellows Gages. Foxboro's absolute pressure recorder utilizes two bellows, the free ends of which are linked together by a tie rod. One bellows is evacuated; the other is connected to the source of pressure. Variations in atmospheric pressure then set up equal opposing forces which are canceled and the record is due only to the absolute pressure of the source.

Bristol's absolute-pressure recorder has a range of 0-5 mm. mercury absolute. The actuating mechanism consists of two extremely sensitive bellows, one of which is connected to the vacuum line being measured and the other directly affected by barometric pressure variations. The movement of the two elements is transmitted by a differential linkage to a single pen arm.

(d 2) Differential-pressure Bellows Gages. The Buckley "Anubis" differential-pressure indicator utilizes a phosphor-bronze bellows across which the pressure acts. The bellows movement is transmitted through the wall

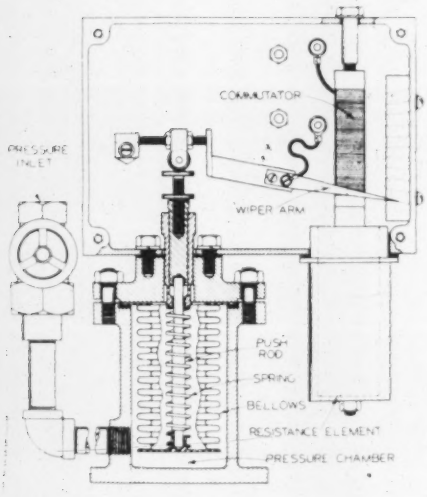


Fig. 2

of the pressure chamber without friction by means of a "torsion tube" the closed end of which is inside the chamber. A lead safety disk is adjusted to blow and equalize the pressure in case the differential becomes excessive. A V shaped groove is formed in the disk which is forced against a pin and ruptured by the pressure. Use of the instrument is possible with working pressures as high as 1000 lbs. in.^{2}.

In a differential pressure recorder introduced by Morey & Jones for differentials from 20" water to 10 lbs. in.^{2} (with maximum working pressure 500 lbs. in.^{2}) the calibrated spring providing the restoring force can be removed easily by unscrewing a plug at the top of the bellows housing. Limit stops are provided to prevent overtravel of the free end of the bellows and zero adjustment may be made outside the case. Motion is transmitted outside the pressure chamber by a steel rod lapped into its bearing provided with a "life-time" supply of grease.

(d-3) Gage-pressure Bellows Gages. Brown's new bellows type pressure recorder, in ranges up to 200 lbs. in.^{2}, utilizes as its pressure element a hydraulically formed bellows balanced against a helical steel spring held on a cup set down in the center of the bellows. Ample pen torque, said to be 15 to 20 times that of a Bourdon tube, is secured by this means so that a change of pressure causes the pen to move to its new position "with a positiveness that seems incredible."

A series of remote-recording pressure gages introduced by Republic for measuring water heads from 10 to 100 ft. utilize metallic bellows with internal spring. Movement of the free end of the bellows causes a wiper arm to slide over a commutator cutting out resistances as shown in Fig. 2.

For aircraft use a General Electric system combines a bellows, a variable-resistance unit and a galvanometer. The copper bellows operates a contact sliding over the resistance unit enclosed with it in a weatherproof, airtight metallic cartridge, out of which lead wires are brought for connection to the indicator. Fifty milliamperes are drawn from a 12-volt battery to supply current to the unbalanced resistance bridge circuit which is designed to compensate for variations in the battery circuit.

An expansive metallic bellows is connected to a Selsyn transmitter rotor by means of a gear sector and pinion in a remote recording system introduced by Bailey.

A special-duty gage developed for recording pressures in oil wells with a maximum permissible error of 0.2% under service conditions is shown in Fig. 3. The pressure element is a long small-diameter beryllium copper bellows in combination with a chrome-vanadium steel spring. A flexible brass bellows acts to separate the oil in the gage from the well fluids which are frequently corrosive. The action of the pressure is to compress the bellows and lengthen the spring. The recording stylus, a finely ground tungsten carbide point, is attached by means of a flat spring to a shaft which extends down through the bellows to the spring attachment. At the point where the shaft passes out the lower end of the bellows, it is fastened by a leak-proof connection. A removable recording unit, Fig. 4, contains a cylindrical chart drum driven by a spring-wound clock. This is placed in the recording housing and given a full turn which inscribes a zero pressure line on the chart. The pressure record is then made as the gage is lowered into the well. A feature of this gage is the use of a thin polished aluminum chart upon which the record is inscribed and which can be read to great precision by means of a microscope comparator supplied with the instrument. This gage is now manufactured by Stupakoff Laboratories in five ranges up to 3200 lbs. in.^{2} with a guaranteed accuracy of 0.2%.

f. Piezoelectric, Carbon Pile, etc.

Space limitations prevent discussing one by one the numerous other types of pressure-measuring instruments.

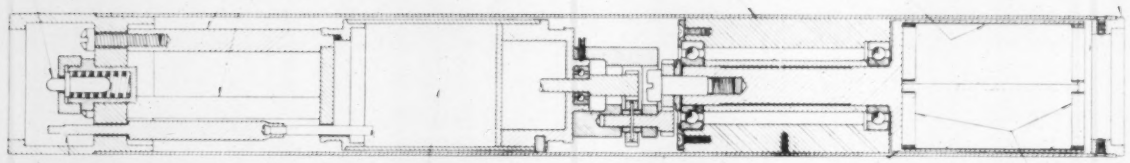


Fig. 4

EDITOR'S NOTE: We are solely responsible for the prominence given Figs. 3 and 4. The author (who shared in the design of this remarkable gage) had modestly left it out.

although not a single type stagnated. The rise of cathode-ray oscillography stimulated research and development in various forms of piezoelectric, carbon-pile (or graphite disk) and other elements which instantly convert a pressure change into an electrical effect; and the number of such elements in use has been doubling itself every year for several years.

II—VACUUM MEASUREMENT

1. MERCURY-IN-GLASS

(a) Barometric and U-tube Types

A vacuum gage brought out by Tagliabue comprises a glass tube closed at the upper end and completely filled with mercury when the cistern is at atmospheric pressure. Two ranges are available, 0-12" mercury and 0-20" mercury.

Another Tagliabue mercury-in-glass vacuum gage is so arranged that in the one leg which would be almost horizontal there is a platinum wire. As the pressure changes the mercury rises on the wire and changes the resistance of its unshorted length. The vacuum is measured by measuring the potential drop across the wire when a constant current is sent through it.

A line of vacuum gages for use in the automotive field has been introduced by Stromberg Motoscope. These are of the U-tube mercury-in-glass type mounted on stands with casters for use in making engine adjustments.

(b) Compression-manometer or McLeod Type

The newer McLeod gages made by Central Scientific feature the elimination of all rubber connections; replaceable and interchangeable glass parts of much smaller dimensions than ordinary and a double range calibrated measuring head of Pyrex glass provided with a mercury cup for sealing its ground joint to the rest of the system.

General Electric introduced a McLeod gage in two ranges, 0-250 microns and 0-2000 microns. Features are a mercury overflow chamber and a heavy-construction cylindrical steel floor stand.

(c) "Evacuated Bell-float" Type

An entirely new principle is employed in the mercurial vacuum gage brought out in 1933 by John Dubrovin, distinguishing it from the U-tube, barometric and compression types although it is akin to all three. It also resembles the inverted-bell (draft gage) type, but with the difference that the space under the bell does not communicate with the vacuum vessel under measurement.

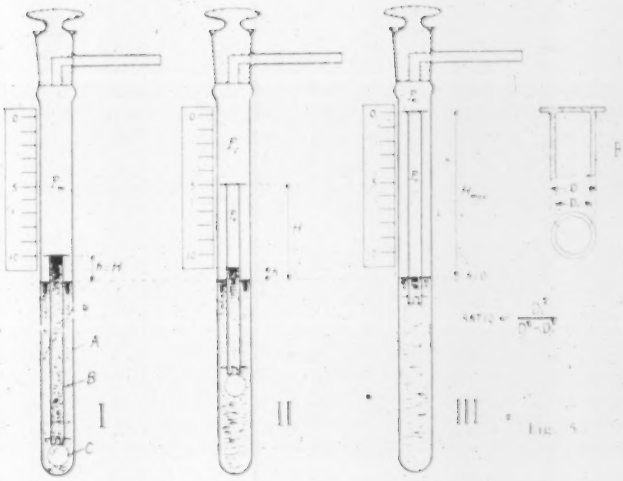


Fig. 5

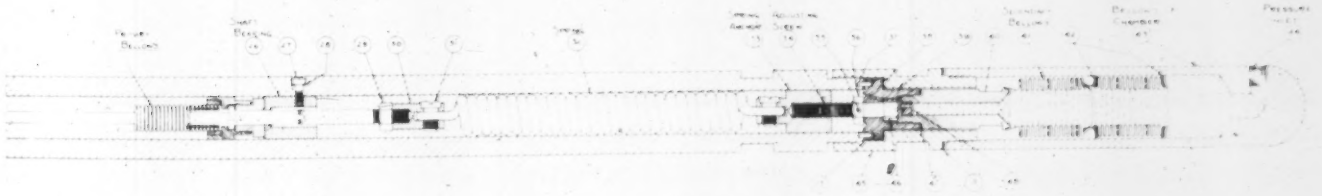
It comprises (see Fig. 5) a glass vessel *A* partly filled with mercury, in which floats tube *B* resting on hollow glass sphere *C*. The top of *B* is closed and it is exhausted; the upper end forms the indicating element of the gage, traveling alongside a graduated scale.

The system *BC* floats at all times. The height *H* of the indicator, therefore, is an inverse-function of the height *h* of mercury inside *B*. Height *h* is a measure of the absolute pressure being measured and its limit, of course, is reached when *B* is completely filled with mercury as shown in diagram I. This maximum *h* is determined by the constants of the individual instrument, as is the maximum value of *H* with no pressure in *A* or in *B* (see diagram III). Thus $(H_{max} - H)$ is a function of the absolute pressure P_a and the relation is linear by reason of the uniformity of the diameter ratios. Likewise, the amplification factor of any gage is determined by its constants, i. e., by fixed dimensions. The meniscus effect and the temperature coefficient are negligible in the commercial models with amplification factors of 6 or 9. The calibration remains constant since the gage employs an absolute measuring principle.

2. MODIFIED PIRANI TYPES

A heated wire in the vacuum to be measured will lose heat at different rates with different pressures. Its temperature and consequently its resistance changes with the vacuum. A Wheatstone bridge circuit is generally utilized, two legs of which are standard resistances in the case and two of which are matched resistors enclosed in glass tubes, an indicator tube and a compensator tube. The indicator tube is sealed to the vacuum system and the compensator is highly evacuated at the factory. Current flows through both filaments, heating them equally when at the same degree of vacuum. The use of the compensator tube enables variations in room temperature to be nullified. Such is the principle employed in a vacuum gage developed by General Electric. Standard ranges are 0-20 microns and 0-100 microns although a special indicator can be supplied for measurements below 0.1 micron.

A similar system is utilized in the Westinghouse vacuum gage, the development of which is described by Lockwood[7]. Two WL-762 electron tubes are used as indicator and compensator in an unbalanced Wheatstone-bridge circuit.



Continental Electric's vacuum gage is of the resistance-bridge type, but in this case one resistance is in air at atmospheric pressure and the other in the vacuum to be measured. A constant current from a 4-volt storage battery flows through both resistances and the bridge is balanced when the indicator resistance is in low pressure. This results in a scale open at the low-pressure end and cramped at the high end, a considerable advantage in many vacuum measurements.

3. VACUUM PRODUCTION

A peculiarity of high-vacuum work is that the same men who are concerned with measurement have charge also of production. Vacuum pumps, therefore, though not instruments, are "instrumentation." The basic principles of the various types had been developed before 1928; the last decade witnessed refinements in each type. Central Scientific's line is now not only complete but consists of units designed to work with one another.

III AUTOMATIC CONTROL

It is unfortunate that space requirements should cause the writer to lump together under one heading such a limited group of descriptions as follow below. Recent years witnessed a great advance in pressure control which may be expressed by Béhar's term "instrumentation" and for which the magazine *Instruments* is largely responsible. In the first section of the first chapter of Béhar's Manual there was published a flat statement, the purport of which was that so-called pressure regulators in the forms of safety valves, reducing valves, etc., are "fittings rather than instruments." Since then he has been harping on the themes (1) that closeness of control depends on the sensitivity of the *measuring* element of the control system, and (2) that the suitability of a control system for any duty depends on the *adjustability* of its other elements. The trend in recent years has been toward replacing the old valve-like regulators by systems with (1) real pressure-measuring elements and (2) adjustable throttling range, etc. Only a few of them can be included in the following brief summarization.

1. PNEUMATIC RELAY

Bailey utilizes a new form of pilot valve operated by a Bourdon tube. Two balls mounted on a rod suspended from a crank arm controlled by the Bourdon fit loosely

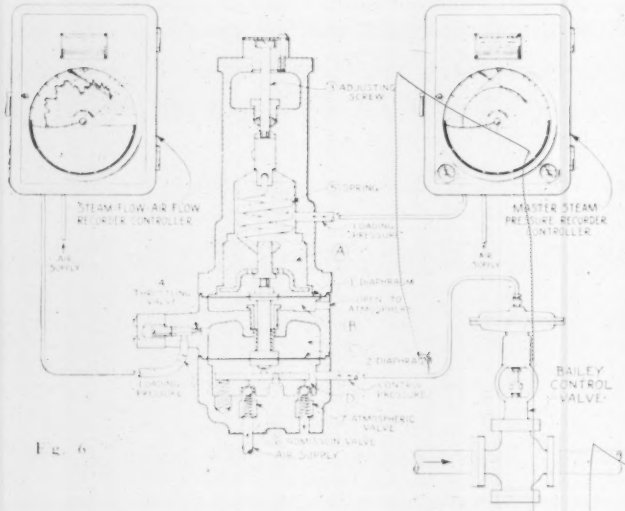


Fig. 6

into the vertical cylinder of the pilot valve. The position of the upper ball determines the pressure in the control pressure line and hence the position of the diaphragm valve. The lower ball on the pilot valve stem balances the effect of the air pressure on the upper ball at all positions of the stem and prevents application of any varying force on the Bourdon tube.

Another Bailey development, the Averaging Relay, serves to add or subtract two or more loading pressures (acting upon responsive elements) and to deliver a control of pressure representing the algebraic sum of the primary loading pressures. In Fig. 6 the "master steam pressure recorder-controller" and the "steam flow—air recorder controller" are both supplying primary loading pressures to the averaging relay. Corrections are made so that the primary loading pressure set up by the steam flow—air flow controller is just balanced out by spring 5 when steam flow and air flow pens coincide one over the other. Should the pens go out of coincidence, the pressure rises or falls in chamber *C* with a resulting change in control pressure as established by chamber *D*. While the master steam pressure controller pressure is applied directly to chamber *D* without throttling, the pressure from the boiler meter is applied through a throttling valve to chamber *C*. This provides for more rapid response to changes in steam pressure than to changes in combustion efficiency.

Bristol introduced a pilot arrangement which likewise imposes no drag upon the Bourdon. It is known as the Free Vane: a thin vane is rotated by the pressure element between two nozzles which discharge opposing jets of air. A secondary pilot valve, controlled through a diaphragm by the air pressure behind the jets, supplies air to the diaphragm motor valve. An adjustable bleeder in the control pressure line enables the controller to be adjusted to the process.

Brown introduced for temperature control a system known as "Air-o-Line" which features independence of measuring and controlling elements, and recently adapted it for pressure control, one of their controllers employing a bell float for close control of low pressures. The "Air-o-line" instrument mechanism is readily adjustable by means of a throttling-range dial and an automatic reset dial.

Consolidated Ashcroft Hancock's pressure recorder-controllers feature a shifting lever by which the regulation may be set either at on-and-off or throttling. The recording part is not affected by the air-operated control mechanism.

Tagliabue pioneered in air-operated systems long before the last decade began. In the last decade they brought out a double-relay arrangement minimizing the drag on the Bourdon, and a throttling-range adjustment, and since then have made further refinements in the way of adjustability to the requirements of the controlled process.

Taylor introduced the fully-adjustable "Fulscope" controller for temperature control applications and have employed this easily "tuned" mechanism in connection with pressure-measuring elements. A feature is a reversible plate whereby high or low-sensitivity ranging may be obtained.

2. HYDRAULIC RELAY

Askania's jet-pipe principle is described in Pigott's paper. One of its adaptations to pressure control is shown in Fig. 7.

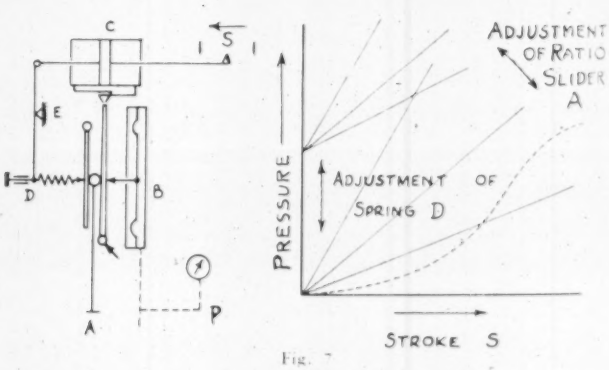


Fig. 7

This is an arrangement to secure a lever movement which will be a definite function of a variable pressure. The Askania solution for this problem offers great flexibility in obtaining different pressure-stroke characteristics to match any desired specification. The diaphragm *B* responds to the varying pressure to move the piston in cylinder *C* until the spring tensi-

balances the force created by the pressure. A change of the ratio-slider position or of the spring D varies the relation as shown in the graph. By using a cam instead of the lever system E, any desired relationship between pressure h and stroke S can be obtained; for example, the dotted line.

Another oil-operated pressure control system is the **IVA Governor** made by Ruths Steam Storage Co. Fig. 8 shows the system arranged to operate as a reduced pressure controller.

Electrically driven gear pump (1) supplies oil under a constant pressure maintained by relief valve (2) to the system. Pressure on the diaphragm (6) causes movement of the double-acting amplifier valve (8) which controls the oil pressure operating the amplifier piston (10). This piston is integral with the pilot valve (11) and compensating pilot valve (12). The pilot valve (11) determines the movement of the valve

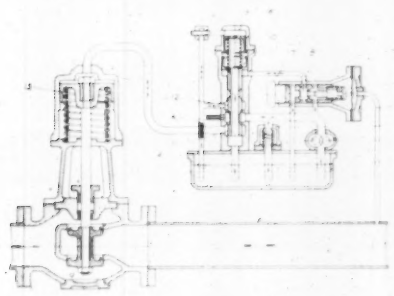


Fig. 8

piston (13) which operates the main governor valve (5). The pilot valve (12) on the other hand controls the movement of the compensation piston (15) which, by means of a spring (16) acts on the amplifier piston (10). Equilibrium is obtained when pilot valves (11) and (12) are in their neutral positions, as indicated in the diagram. Two constrictions, K_1 are so dimensioned that a balance is then obtained by the compensation piston (15) and amplifier piston (10), at the same time amplifier valve (8) is in its intermediate position. This corresponds to a definite deflections of diaphragm (6), therefore steam pressure in main (4) may readily be adjusted by changing relative position between the amplifier valve (8) and the diaphragm (6). Adjustment is accomplished by turning wheel (17), which can be done during operation. This system is said to work without hunting, even under the most severe conditions.

3. ELECTRO-MECHANICAL

Recent developments in potentiometer recorder-controllers, etc., are no doubt described in other "Decade of Progress" articles, since these systems were primarily developed for control of temperature, pH, etc., rather than pressure. The writer will describe only two recent controllers designed specifically for pressure control: a simple one and a relatively elaborate one.

Meriam brought out a mercury-in-glass manometer with tungsten lead wires adjustably mounted in each leg so that electrical contacts may be completed at predetermined maximum and minimum values of pressure or differential. Third wire connection is made to the mercury by means of the iron block which forms the connection between the two manometer legs.

The Main Regulator made by Shalleross Controls, Inc. comprises a pressure switch of the diaphragm or gasometer type, actuated by the pressure to be controlled. Contacts of the pressure switch control the speed and position of the regulating butterfly valve. The actuating beam of the pressure switch is balanced by both a fixed counterweight and a light loading spring. One end of the spring is attached to the switch beam and the other end wound on a small drum operated through differential gears from *two* motors:

Motor No. 1 is a high-speed primary compensator rotating proportionately to the regular motor. When changes in the tension of the loading spring occur, this forces the contacts back to neutral, stops the regulator motor and itself, and establishes a "new normal." This primary compensator prevents overtravel and hunting. Motor No. 2 is a low-speed, secondary compensator. It operates the reverse of motor No. 1 to restore the pull of the loading spring to its original tension and brings the "new normal" back to the desired constant pressure. This secondary compensator maintains a uniform normal under all conditions of flow or demand.

BIBLIOGRAPHY

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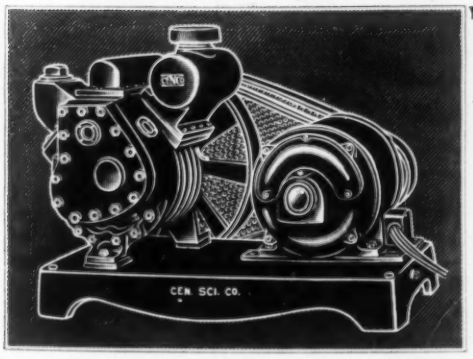

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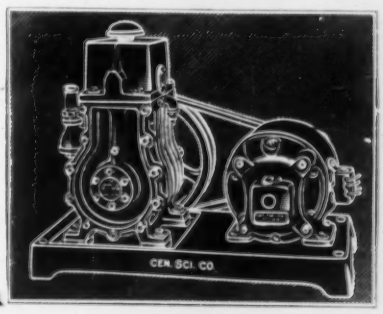

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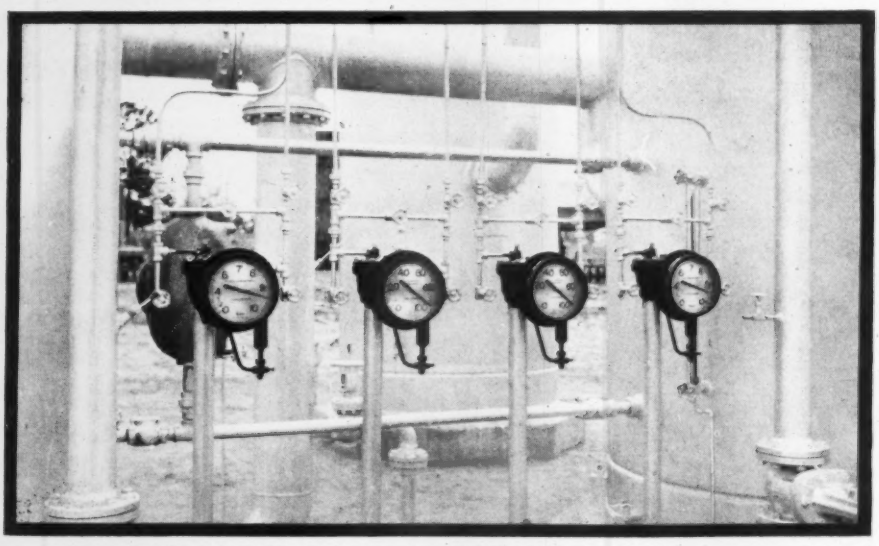
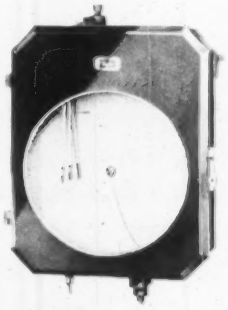


Showing Taylor Flow Indicators which measure lean oil to, and gas flow from, absorbers in a Louisiana gasoline plant.



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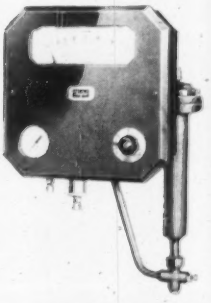

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TEMPERATURE, PRESSURE, FLOW —*and* **LEVEL INSTRUMENTS**

A DECADE *of* PROGRESS *in*

Industrial Fluid Metering and Automatic Control

By R. J. S. PIGOTT

Staff Engineer, Gulf Research & Development Co., Pittsburgh, Pa.; Chairman A.S.M.E. Fluid Meter Research Committee since 1916; Vice-President A.S.M.E.

IN the past ten years all forms of fluid measurement advanced considerably and their industrial applications multiplied, for two reasons: first, better appreciation of the dollar value of accurately known quantities and rates in all processes (beside water supply, power and gas, where metering was first appreciated); second, much improvement in commercial accuracy of measurement, for the rate-of-flow meters ("flowmeters"). This decade witnessed also a growing appreciation of the advantages derived from automatic control of industrial fluids:

(1) Predetermined quantities by (a) gravimetric and (b) volumetric cut-offs;

(2) Automatic control of flow-rate with primary elements responsive to (a) weight-rate or (b) volume rate.

Here, too, as is apparent from this four-fold classification, advances in metering led to progress in automaticity, because the satisfactory performance of control systems depends largely upon their primary measuring elements. This review, therefore, will deal mostly with advances in the *metering* of industrial fluids.

I QUANTITY ("Positive") METERS

Positive* quantity meters comprise two classes: weighers and volumeters. Weighers still find their principal applications in the measurement and control of *dry* materials and of semi-fluids. This being dealt with in another "Decade of Progress" article, we need only mention that in the field of industrial liquid weighers there have been no real innovations; only refinements in the Cochrane, Richardson and other makes. There have appeared some ingenious small liquid weighers for research purposes, among them a precision fuel weigher used in the writer's gasoline engine laboratory, but this review is limited to industrial applications.

Volumeters still constitute the great majority of quantity meters. For liquids the positive displacement types (pistons, disks, etc.) greatly outnumber the gravitational volumeters (tank and drum types) in spite of the appearance of small tank volumeters such as the new (1937) "Vesta."

POSITIVE DISPLACEMENT LIQUID METERS

In the displacement volumeters no new types appeared, and improvements were confined largely to:

(1) Better choice of materials (particularly in the corrosion-resistant group) to reduce corrosion, with associated wear, sticking and impaired accuracy, and to reduce mechanical wear by better bearing qualities;

(2) better fits and proportions to reduce wear;

(3) more convenient adjustment to maintain calibration.

The long controversy in piston meter design as to whether soft packing (usually leather), metallic packing (rings), or capillary packing (close fit) is best, remains unsettled. No definite superiority has been proved for any of the three, and good meters are built, packed in each of the three ways.

The Pittsburgh Equitable piston meter and the Bowser use soft packing; the Brodie, Universal, Badger and Bassler are capillary packed; the Oceco "Micro" and Brodie Model X are ring packed. All are equipped with stroke stops for calibration adjustment; the Bassler has a temperature compensator which also adjusts stroke so as to reduce the readings to selected base value (for example 60 F.). Bowser brought out in 1936 a meter driving a small magneto, whereby remote indication and recording of flow *rate* is obtained.

The oscillating piston types, exemplified by Neptune and Empire, are capillary packed (close fitting), the general design largely ruling out any other method of sealing. The design permits low cost accurate quantity production, using hardened and ground parts, resulting in extremely long life between repairs or recalibration. This type, however, while quite accurate at moderate rates of flow, shows more error at low flows (below 5% of rating) than the piston meters.

The nutating disk meters have not been changed except for some improvement in materials and details.

There appeared in 1933 an ingenious auxiliary, the "Gulper," wherein small flows accumulate first and then pass through the meter at a flow-rate sufficiently large to be registered accurately. At rates above 1 g.p.m. the liquid passes directly through the meter.

One vane-type meter showing good characteristics of low head loss appeared, but its first form was not of satisfactory durability. No doubt it will be improved in later designs, as the type offers advantages; the construction is well adapted to the use of hardened and ground parts easily made in quantity production; and it affords better capillary sealing than any type with the possible exception of the piston meter.

A greatly increased demand for measuring crude oil, at individual wells and elsewhere, is likely to open up a modified but difficult field of liquid metering. Inferential meters have not shown marked success, as flow conditions are generally the worst for a disk orifice or venturi, and for pipe lines the change of gravity and viscosity has proved troublesome in correcting the readings. The volumeters have an excellent chance of meeting these conditions, provided they are built to withstand small quantities of said, sulphide corrosion, and salt water. The big problem is proper separation of water, and bottom settlings; and the removal of gas to the point where none is pulled out of solution in the meter. If the volumeter manufacturers plunge into this field without carefully working out the solutions to these difficulties, they will be in plenty of trouble.

POSITIVE GAS METERS

For gases, the bellows meter has grown from the older tin case and C.I. low pressure meters into pressed steel and heavy C.I. construction for pressures up to 300 lbs. in.^{2}. Changes are otherwise details, consisting of

* This term is no longer used in the new edition of the A.S.M.E. Fluid Meter Report but the concept of "positiveness" remains a good one for industrial instrument engineers to bear in mind. See Babal's discussions of this subject in *Instruments*: Nov. 1932, pages 263-264; Dec. 1932, pages 279-282; May 1934, page 104. Citation of these references does not imply, of course, that the writer agrees on all points.

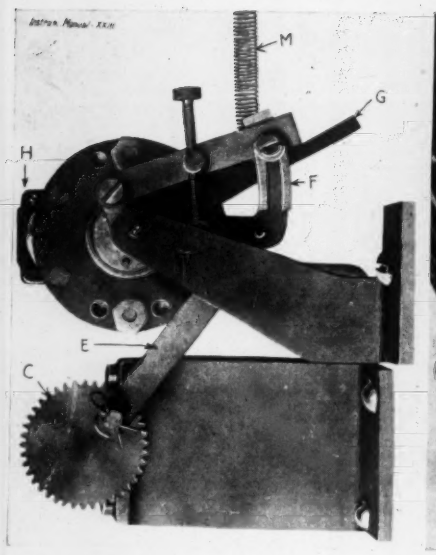
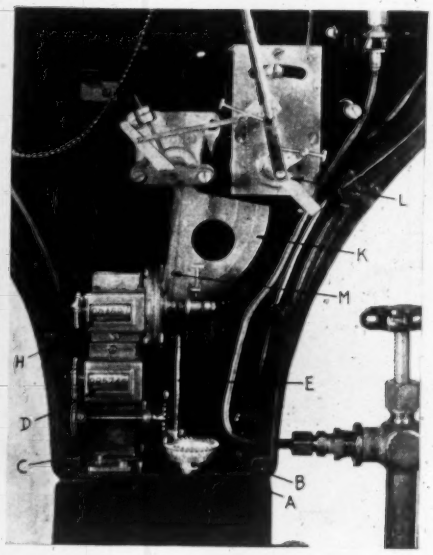


Fig. 1



The Emcorector

Fig. 2

Drive shaft *A* from the meter operates regular counter *D* through crown gears *B* and *C*, reading actual cubic feet at meter pressure; gear *C* by link *E*, oscillates segment *F*, which in turn operates arm *G* on down stroke; arm *G* is returned by spring *M*. Cam *K*, bearing on the outer end of *G* and connected to pressure element *L*, limits the back stroke of arm *G*. Arm *G* operates counter *H* through a toothless ratchet, reading in cubic feet at base conditions. It is easy to see that as pressure in the meter rises, cam *K* is rotated to increase the stroke taken by *G*, and reduces it for a fall of pressure, thus correcting the reading of *H* to base pressure, from *D* reading. Cam *K* is cut to give not merely a constant pressure correction but is altered to give the correction for deviation from Boyle's Law.

improved valve and seat materials for longer wear with low leakage, and better bearing design throughout. Some larger meters now incorporate external lubricating means for major rubbing surfaces, some of which are now equipped with ball or roller bearings. The principal innovation is the addition of mechanisms to reduce meter readings directly to base values of pressure and temperature. The Emcorector (Pittsburgh Equitable Meter Co.), is shown in Figs. 1 and 2. No temperature correction is applied, but it is obvious that it could be, by adding a temperature element, and suitable bridle linkage between this element and pressure element *L*, so that cam *K* would be moved for net effect of temperature and pressure. The American Meter Co. produces "base volume and pressure indexes" typified in Fig. 3. The same construction is used for integration in their orifice meters, but a volume element (temperature) replaces the "differential" element when used for volumeters, and the helical cams are a different shape, since in this case they are correcting first power effects instead of square roots. Such cams, of course, can be cut to yield powers or roots, or any deviation from a single-power function such as change of coefficient with Reynolds number, or deviation from Boyle's law.

These two devices illustrate the growing tendency to amplify the character of flow measurements so as to minimize manual operation. Both include the regular cubic foot counter for meter conditions, so that if a pressure and temperature recorder is used with the meter, the corrected base readings can be checked and substantiated. They reduce clerical work, possible errors, and sometimes arguments over contract quantities.

The test types of volumeters (the liquid sealed drum) and the gasometer have not undergone any major change. The lobed impeller type (Roots-Connersville) is now available in a small size: up to 5000 ft.³/hr.

II—RATE ("Inferential") METERS

The other great group of industrial fluid measuring devices, the "inferential" group, comprises venturis, flow nozzles, orifice plates, weirs, area types, etc. In the oldest of these devices, the weir, the primary element has not been changed, and the secondary elements are generally the same as those used with orifices and venturi tubes.

Builders Iron Foundry brought out a modified shape of venturi tube with up-stream contour having a curve similar to a flow nozzle, and with controlled roughness in the approach. The purpose of this design was to flatten out the coefficient curve so the "flat" value for high Reynolds number flows was brought down to a much lower range. There is now a stronger tendency to move toward controlled roughness in all the tubes. In addition, shorter diffusion cones are now provided both by Builders Iron Foundry and Simplex Valve & Meter Co. These take less space in the lines, but sacrifice some of the recovery of the velocity head. The older long diffusion cones yielded the highest recovery (85 to 88%) of the velocity head, of any of the primary devices.

The flow nozzle and the disk orifice have grown up more or less together. Probably the first regular user of the flow nozzle was General Electric, who abandoned the Pitot tube type in favor of the larger head device some years before they turned over their flowmeter business to Bailey.

The Bailey Meter Co. uses venturi tubes, flow nozzles, or orifices as primary elements, depending on which is best suited to the service; it is the only company at the present time that makes use of all three.

The American Meter Co. and Bailey Meter Co. brought out wide-range adjustable orifices of the segmental type, for unusually wide flow

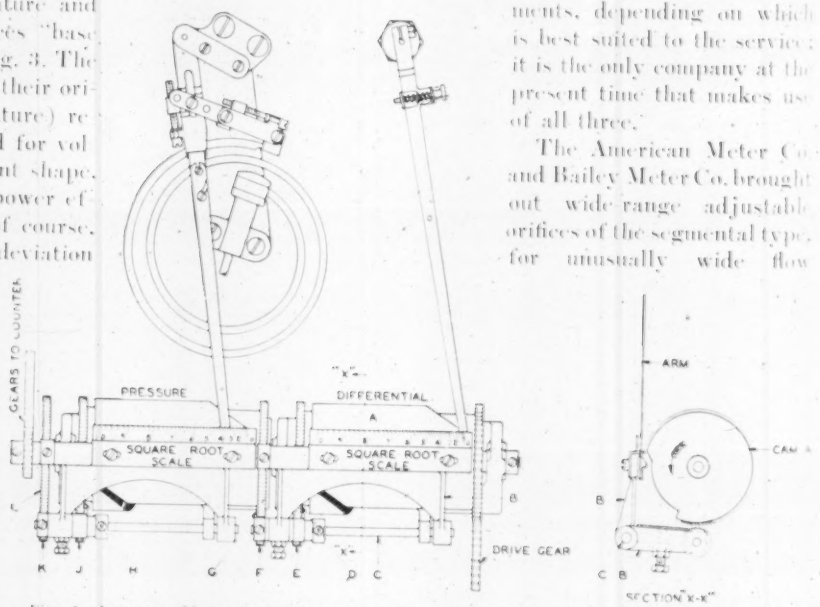


Fig. 3. American Meter Co.'s Mechanism. Cam *A* is (in the case of the volumeters) driven by the meter directly; its surface is cut with increasing percentage of high land per revolution. The corrective element pen-arm is interposed between cam *A* and rocker lever *B*, pivoted at *C* and carrying gears *E* and *F* on the other end of the rocker. When the high land of the cam is opposite the pen arm, it raises rocker lever *B*, through the pen arm, and engages gears *E* and *F* with gear *D* on the output end of the cam, and with gear *G*, which will be on the base condition counter if only pressure correction is used, or on the second element cam input end for the double correction. If both temperature and pressure corrections are made, the first cam is temperature, the second pressure. The net effect of the two corrections in series is a complete density correction to standard or base conditions.

ranges. The former is manually adjusted to 60 locked positions; Bailey's can be equipped for automatic change when desired, involving no manual operations. Another useful addition is the complete flow nozzle or orifice pipe, for pipe sizes 2½" and smaller. The great advantage is elimination of faulty or difficult pressure taps, and the provision of an upstream section of known and definite smoothness, which is of major value in bringing the coefficients into line with those in the larger pipes.

Orifice fittings were brought out permitting changing disks without shutting down the line. Meriam has just brought out a combination of a U-tube manometer with a fitting having a rotatable four-orifice plate.

Pitot tubes were refined and brought nearer standardization. Some centrifugal element advances made engineering history, but these fall outside the industrial scope of this review.

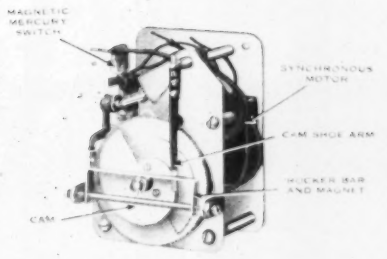


Fig. 4 - Chronoflo Transmission

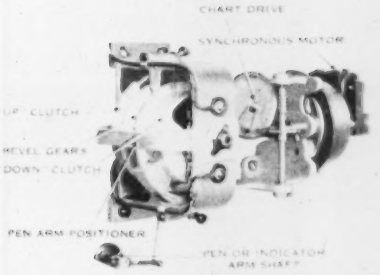


Fig. 5

A spiral cam, rotated by a synchronous motor, is associated with a cam shoe arm (see Fig. 4) positioned by the mercury U-tube float. The cam shoe arm, when riding on the high surface of the cam, operates a rocker-bar which carries a permanent magnet, and this in turn operates a mercury switch. The length of time per cam revolution that the cam shoe arm rides the cam determines the duration of the current transmitted to the receiver for advancing indicator hand, pen, or totalizer. The receiver (Fig. 5) contains a synchronous motor driving two magnetic clutches in opposite directions. When the transmitter circuit is closed, a relay is actuated to energize the "up" clutch. When the circuit breaks (from the cam shoe arm dropping off the cam in the transmitter) this clutch, eccentrically weighted, drops back to starting position and the "down" clutch is magnetized and rechecks the pen or dial hand position just established by the up clutch. The same power is available at all positions.

SECONDARY ELEMENTS

Hundreds of new flow instruments appeared in 1928-37. They were all described in this magazine, so that an exhaustive review is unnecessary; each was described *by itself*, so that a quick survey of some trends is apropos.

In glass manometers one trend was toward high pressure construction; another toward making the industrial forms as capable of high precision as laboratory models. For details see Exline's review of pressure instrumentation in this issue.

The Westcott orifice meter of American Meter Co. is now equipped with an integrator of the interrupted type, which was described on the facing page as the Pressure and Volume Index. The construction is the same, except that the first cam extracts square roots; the second corrects for pressure variation. Fig. 3 shows the actual construction. The recorder charts can be furnished with square root scaling so they read direct in flow.

Builders' new Chronoflo, Figs. 4 and 5, is a long distance electric transmission of the manometer float position to indicating, recording and totalizing instruments. The earliest such electric transmissions were probably Republic's of over twenty years ago (wherein the mercury level varied the current transmitted to electrical indicators, recorders and integrators) and the induction-balance methods of Bristol (1912) and of Brown; but the Telautograph system (over 30 years old) is really the first "position" transmission. The Chronoflo most nearly resembles in principle the time impulse long used by Leeds & Northrup or the Bailey adjuster used for micrometric controls on some combustion regulators.

One must distinguish between (*a*) an electric flowmeter designed as such, and (*b*) an instrument originally designed as a differential pressure gage with square root extraction and later hooked up to an electrical telemetering system bought by the instrument maker from an electrical instrument manufacturer. This is the usual history, but at least once during the last decade it happened the other way: Designed as a flow transmission, the Chronoflo is now being marketed by Bristol as the Metameter Electrical Telemetering System under which name it is being installed by electric power distribution engineers who never dream of its hydraulic-engineering genesis! But let's get on with other recent electric flowmeters.

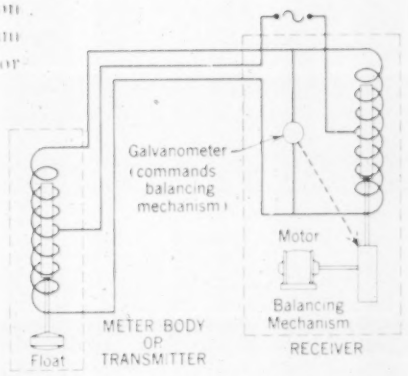


Fig. 6

Cochrane's new induction-balance system, Fig. 6, does not depend upon plunger pull at the receiving end for moving the pen arm and operating the integrator; balance between transmitting and receiving electrical elements is forcibly restored by a servo motor commanded by a galvanometer which detects unbalance between the pairs of variable inductances. In the Electruflo of Morey & Jones, Figs. 7 and 8, balance is forcibly restored by a motor-driven cam acting upon the magnetic element of the receiver.

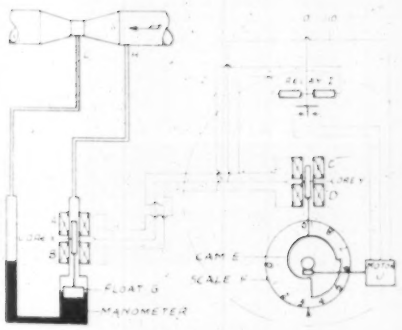


Fig. 7 The Electruflo

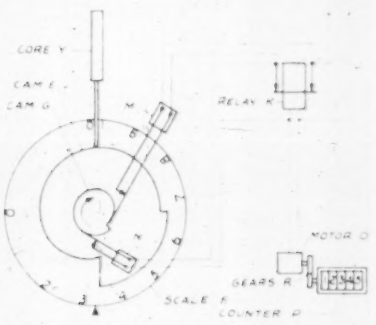


Fig. 8

Cam G rotates twice a minute. Contact M (Fig. 8) is stationary and starts motor O. Contact N revolves with cam E and indicating scale F and stops integrator motor. Relay K holds circuit closed after contact M has opened and until cam G opens contact N. Duration of motor operation is thus proportional to flow-rate.

American Meter now provides a long distance electric transmission of the Selsyn motor type. The transmitter consists of a regular Westcott differential gage with an indicator, which operates the Selsyn sender. The receiver is simply the Selsyn receiver operating the pen arm of the recording integrating meter mechanism. These meters are furnished in five regular differential ranges from 2½" to 110" water in suitable steps, and special ranges when required.

Tagliabue also provides a long distance

transmission, using the position-motor system.

Taylor furnishes a line of instruments with mechanism substantially identical with the American Meter line, with some extension into purely indicating simpler forms.

The recent Type M instrument of Builders is a redesign of the older register recorder, retaining the large floats and cam type square-root extraction, indicator and recording charts, uniform graduation in flow units.

The traction wheel drive is retained in the totalizer, which may be provided with mechanical or electric drive. The Flow-watch secondary is a considerable departure. The float travel is less, and the whole instrument is reduced to the ordinary dimensions for panel mounting. The cam square root extraction is retained, but the totalizer is of the "interrupted" type now becoming common. A spiral cam driven by a Warren clock gives a stroke motion which in turn operates the totalizer through a second lever whose motion is limited on the back stroke by the position of the pen arm. In principle it is precisely the same as the Emcorrector and Metric Base Indexes previously described. This method of integration eliminates slip and vibration errors found in the older traction roller types.

Simplex Valve & Meter Co. were the original users of the Ledoux conoidal bell. Bailey Meter Co. also uses this excellent type of square root extractor, which eliminates all cam or interrupter types of mechanism, and in general simplifies the transformation of head to flow movements. Bailey's principal secondary element, or "flow mechanism" still uses the Ledoux bell in its original form (Type C) Fig. 9. For moderate and low differentials, a conoidal float "reversed" from the Ledoux bell is shown in Fig. 10. This type is the counterpart of one built by the writer in 1909 but never produced commercially. In both cases, square root extraction is directly by the float, so that pen-arm motion is directly proportional to flow, and all charts are evenly spaced in flow units. The traction wheel integrator has been replaced by an interrupted or escapement type, Fig. 11. This figure, showing two positions on the cam for zero, 150% and 100% of flow, illustrates quite clearly what takes place. This integrator operates by tending to rotate the counter at the full-flow rate; the pawl control from the pen arm "holds back" part of the full flow rotation of the escapement wheel, slipping the friction drive, so that the net movement corresponds to actual flow.

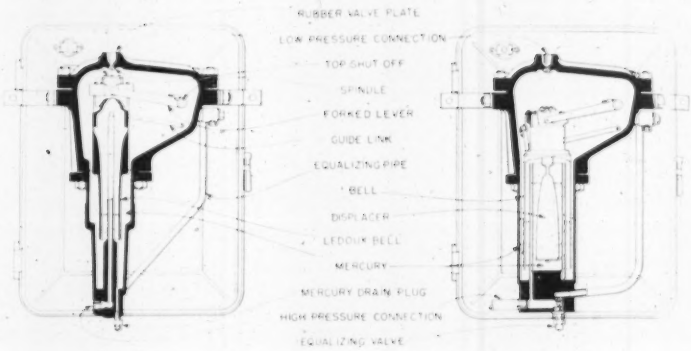


Fig. 9 Fig. 10

While on the subject of conoidal tubes and bells, we may mention an Askania secondary element, Fig. 12, introduced to the U.S. in 1932. It measures flow rate by weighing the quantity of mercury displaced from high-pressure leg 4 (said to be "parabolic") to the spring-balance arrangement 5, the indicating scale of which is said to be uniformly graduated in flow rate units by virtue of the "parabolic" liner in the unweighed leg. The use of an "external" measuring spring also deserves mention in the opinion of the writer, who has had to solve problems arising from elastic elements subjected to high temperatures and corrosive conditions.

Tagliabue's new secondary elements provide square-root extraction by a conoidal-bore leg in a mercury U-tube, so that float movement is proportional to flow. A magnetic coupling transmits motion of the differential shaft to the pen arm shaft outside the housing, without using a packing. Packing friction is entirely eliminated but the claim that the drive operates the pen "as positively as a rigid mechanical coupling" is not true: any magnetic coupling without metal-to-metal contact requires some displacement to develop torque. Displacement can be kept small enough to be insignificant by designing the magnets powerful relative to the torque load.

This method of avoiding packing was used in the G.E. PS5 meters twenty five years ago.

An interesting packing-less method was

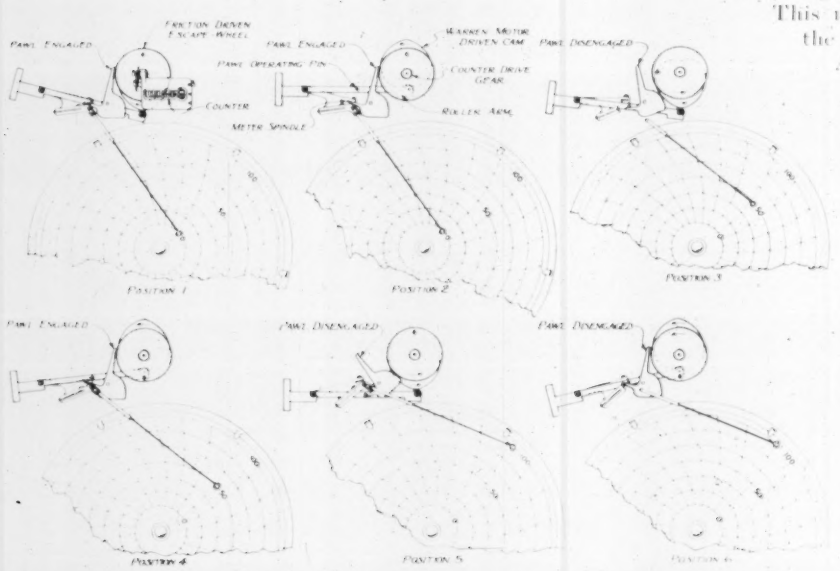


Fig. 11. Bailey Mechanism. A Warren motor drives at constant speed a heart-shaped cam continuously and, through a friction drive, an escape wheel which operates the counter. A roller arm is pivoted at its outer end on the meter flow arm; at the other end a roller engages the cam, which oscillates the roller arm twice a minute. Midway between foot and roller is a pawl operating pin which can engage tail of the pawl which in turn may engage the escape wheel. This pin, together with the position of the pivot on the flow arm, determines how much of the cam revolution the pawl will engage the escape wheel.

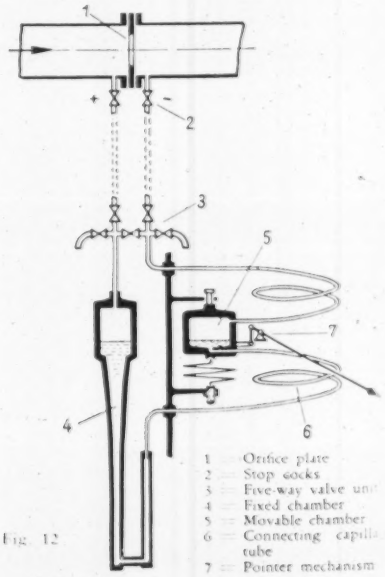


Fig. 12

1 — Orifice plate
2 — Stop cocks
3 — Five-way valve unit
4 — Fixed chamber
5 — Movable chamber
6 — Connecting capillary tube
7 — Pointer mechanism

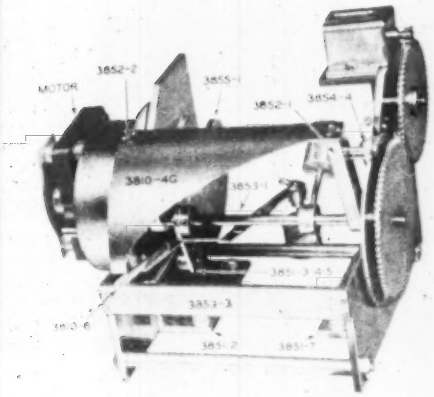


Fig. 13 Mason-Neilan Mechanism

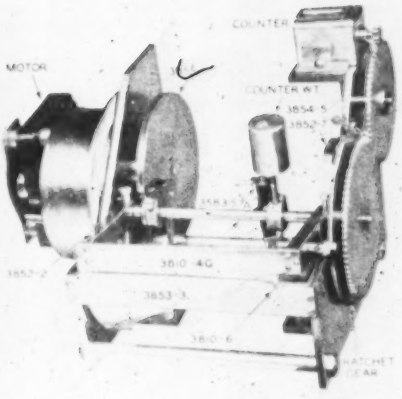


Fig. 14

Synchronous motor driven cam 3855-1 rotates at 2 r.p.m. When roller arm 3851-3, c. 5 drops into the notch in this cam, it drops square root cam 3810-4G downward by gravity past the stop-bar 3853-3. Intercept pointer 3810-6 is positioned on top of the stop bar, and under the cam surface of 3810-4G; its position determines the extent of cam drop. As the roller arm rides out of the notch in c.m 3855-1, it lifts the square cam back to neutral position. The right connecting arm of cam 3810-4G carries a pawl 3854-4 which engages the ratchet wheel on the down stroke, driving the counter. Check pawl 3854-5 prevents reverse rotation on the return stroke; shield-3852-" provides for adjusting point of initial engagement of the drive pawl.

developed out in Los Angeles by Colonel Binckley, and embodied in his "Anubis" flow indicating and recording instruments. He not only uses a spring bronze bellows in a pressure chamber but also an elastic "torsion tube" with its closed end in the pressure chamber, so that there is neither stuffing box nor any metal-to metal rubbing contact, "all motions being elastic deformations."

Returning to mercurial instruments: Mason Neilan brought out a line of flow instruments with concentric tube manometers (one leg inside the other). Their interrupter type integrator is shown in Figs. 13 and 14.

Foxboro's line had been brought out before the last decade began. It was rounded out by the addition of a low-pressure (bell-float) secondary, and of a "Universal" recorder with four pens: rate, pressure, temperature and quantity increment.

Leeds & Northrup have contributed a departure from common methods in the Centrimax integrator, Fig. 15. Upon examination it is not as new as might appear, but is largely a combination of old elements in an ingenious new way. The use of the tilting U-tube was originally made in the first G.E. "baby carriage" flow recorders, about 1909. The same knife-edge and coil tube pressure connections were used. Later, around 1920, Cochrane brought out their tilting U tube instrument with the connection tubes in torsion, and in addition a square root extraction method that did not involve any friction, consisting simply of a tape-suspended weight rolling on or off a cam rigidly mounted on the tilting U tube. Smoot in 1923 brought out a stoker-engine speed control that balanced regulator loading varying as square of flow with a centrifugal oil-cup in which liquid pressure varied as square of speed. (His earlier layouts used the fly ball governor, but the liquid cup was simpler and involved no friction.) The real departure is in the introduction by L&N of the null-method in flow metering, and the reversal of the usual order of registration—in this case integration first, indication or recording afterward. Fig. 15 shows the method. As mercury rises in one leg of the U, balance, tending to upset balance, the mercury switch is thrown, energizing the motor operating the fly ball system. As this speeds up, the restoring force is proportional to square of speed; therefore

head : restoring force :: flow : speed

As the balance comes to level, the switch cuts out. The effect is that the motor is "jabbed" to an average speed corresponding to flow, and operates a counter through suitable reduction. For distant indication or recording, an electric tachometer is incorporated with the fly-ball system, and for distant integration, an impulse counter is operated from a cam on the motor totalizer shaft.

Cochrane's tilting U tube meters and their recent induction balance line were supplemented a year ago by a mercury and float line of conventional design. Fig. 16 shows the integrator.

The most important advances in the orifice, flow nozzle and venturi group have been the result of joint research by users and manufacturers. About ten years research carried on by the A.S.M.E. and A.G.A., with the National Bureau of Standards directing the experimental program, has culminated in full reports establishing orifice coefficients on a firm basis for all types of taps, ratios and pipe sizes. At present, the A.S.M.E. Special Research Committee on Fluid Meters is completing a similar program on flow nozzles, with the Bureau of Standards again directing experiments. In addition, the newly issued report of the same committee has collected the fullest data on approach conditions as to roughness and distortion of flow.

Manufacturers of meters had punished themselves (and often their clients) in earlier years, by permitting the buyer to make incorrect installations. It is now realized that the meter does not consist merely of a primary and secondary device, but also of the pipe ahead of the meter, and the condition of the approaching stream. Approach flow distortions must be corrected by straighten

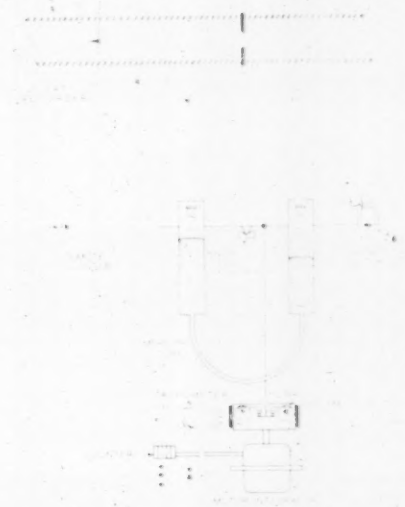


Fig. 15. The Centrimax.

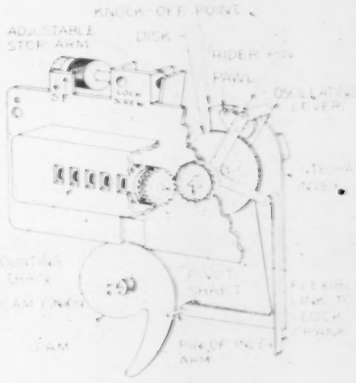


Fig. 16. Cochrane Integrator. Float motion is transmitted through sector to pinion on cam shaft. Cam is shaped to extract square root. A pin on integrator index arm rides against cam, so that index arm position corresponds to flow rate. An oscillating lever driven by instrument clock carries a pawl-and-pin riding on the integrator index. When pin reaches knock-off point, pawl engages with and advances a disk mounted on first staff of counting train. On return stroke, pawl rides freely over disk. Cycle is repeated every minute.

ing vanes or other means, and pulsations must be adequately damped and roughness controlled, if consistent coefficients and performance are to result. Numerous installation devices were brought out. American Meter Co. furnishes an intermediate pressure connection, shown in Fig. 17. This type of connection obtains mean between up and down stream pressure by means of two identical capillary tubes. The use of such connection greatly extends the range of differential possible without applying compressibility corrections.

AREA METERS

Cylinder and piston type area meters had been brought out by New Jersey Meter, Spraco ("Vaughan") and Ingersoll Rand before 1928. In the last decade Pittsburgh Equitable brought out a self contained indicating form for gas; Eclipse Aviation a self contained indicator for aircraft fuel lines; Lambert Meter a self contained recorder, for gas; and Brown Instrument a long distance electric system (induction balance principle) for liquids.

Early in the decade Schutte & Koerting brought to this country the free float type, known as Rotameter. Its simplest form, a free float in a tapered glass tube, is suitable only for clear liquids or gases, moderate temperature and pressure. It has a wide range of accurate flow measurement, in common with all meters of this type. Rotameters are now made in the U.S. by Fisher & Porter. An indicating recording totalizing Rotameter is shown in Fig. 18; the principle employed is that of the variable core transformer and the instruments are essentially millivoltmeters.

Fig. 17

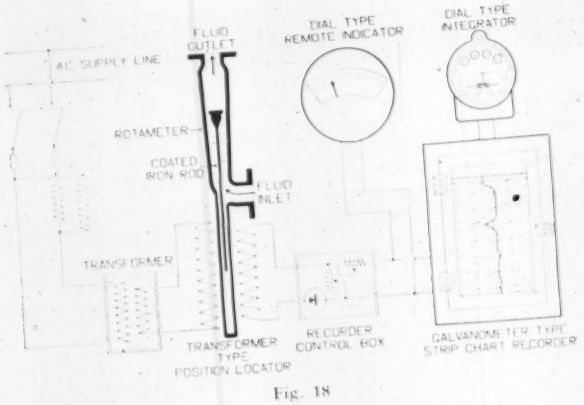


Fig. 18

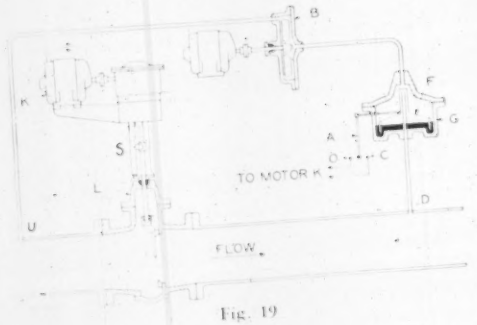


Fig. 19

In the above types of area meters, constancy of head is simply maintained by the weight of the flow-restricting element itself. There also appeared "head regulating" types in which upstream and downstream pressures act upon a power device—directly as in the Isometer (Elgin Softener Corp.); indirectly as in the Linderman Meter (American Meter Co.). The latter, Fig. 19, is for accurate gas measurement where load varies considerably and where totalization is to be compensated for temperature, pressure, specific gravity and rate of flow.

The differential is measured by a bell float manometer provided with contacts whereby the motorized valve is operated. The setting point of this differential controller is automatically varied by a density element consisting of a constant speed blower. (The differential produced by a constant speed blower is directly proportional to the instantaneous density of the gas which depends on its temperature, pressure and specific gravity.) These elements are so adjusted that the orifice differential and blower differential are opposed, so that the differential gage "reads zero" and that the average speed of the gas over the area of the variable orifice is always 8100 ft. min. The result is measurement of gas quantity at line conditions. This quantity is then corrected for line temperature and pressure by means of a mechanism similar to the one shown in Fig. 3.

VANE (FORCE) METERS

Eclipse Aviation brought out a fuel flow meter with a swinging vane primary element and a Selsyn motor system for transmitting the indication from fuel line to instrument board. Illinois Testing Laboratories brought out in several forms the small portable direct reading Velometer for ventilation work. Powers Regulator brought out an extremely simple ventilating fan regulator consisting of an aluminum vane actuating a pilot valve; and the Autocall Co. an even simpler one of the electric contact type.

CURRENT (VELOCITY) METERS

The controversy between proponents of cup and screw types of water current meters continued to rage and resulted in makers of both types refining their products, as did makers of the turbine type. For air, the previously available anemometers were likewise improved; and the Mine Safety Appliance Co. brought out a new one wherein a tachometer reading directly in miles per hour is driven by the rotating element (a modified cup type) which is non-directional. This of course is a light portable anemometer. In the field of permanently installed current meters, innovations in the hydraulic types consisted of direct reading systems; and progress in the wind velocity types was stimulated by the multiplication of airports for which Friez (Bendix Aviation subsidiary) brought out remote-indicating systems.

THERMAL METERS

The popularity of thermal meters for gas measurement seems to have declined as relatively inexpensive meters of other types multiplied in the last decade. There appeared in experimental form a "miles-per-gallon" automotive fuel meter employing the thermal principle in modified form: heat is supplied by electrically heated wires as in the well known Thomas gas meter, but the instantaneous rate of heating is not constant; it is proportional to the speed of the vehicle.

III—CONTROL

"Automatic control of industrial fluids"—the third subject assigned to the writer—can be interpreted so broadly as to include about 80% of automatic control devices in industry. All liquid level controllers, for example, are "flow controllers." So are most temperature and pressure controllers. Under this broad interpretation it would take a large book to report the last decade's progress. One phase of this progress, however, has been a greater appreciation of the principle that before a condition can be controlled it must be measured, which implies that an automatic controller must embody a measuring element. This brief review will be confined

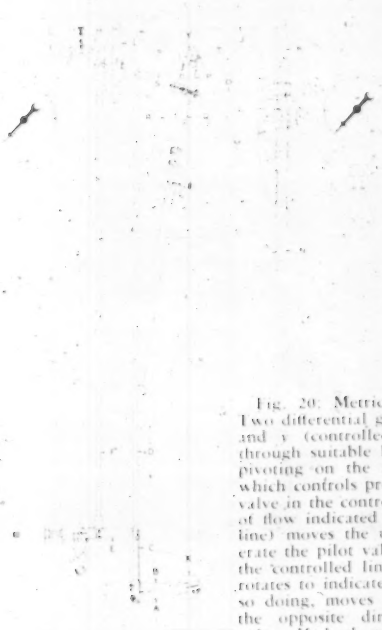


Fig. 20. Metric Proportional Control. Two differential gages, x (governing flow) and y (controlled flow) are connected through suitable levers to bridle link K, pivoting on the arm of pilot valve M, which controls pressure to the diaphragm valve in the controlled flow line. Increase of flow indicated by x (in the governing line) moves the upper end of K to operate the pilot valve and increase flow in the controlled line; as flow builds up y rotates to indicate increased flow; and in so doing, moves the lower end of K in the opposite direction, bringing pilot valve M back to equilibrium position corresponding to the new proportioned flow. Proportional changes are accomplished by changing the setting of H on arm G. Liquid level may be controlled by the same kind of arrangement.

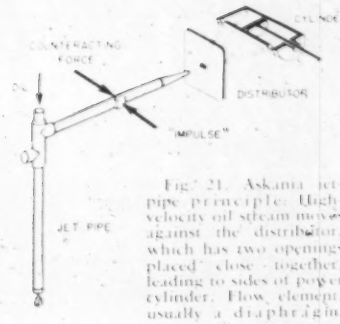


Fig. 21. Askania jet-pipe principle. High-velocity oil stream moves against the distributor, which has two openings placed close together, leading to sides of power cylinder. Flow element, usually a diaphragm, moves jet pipe more fully over one opening or the other; the jet by impact produces pressure and flow into one side of power cylinder.

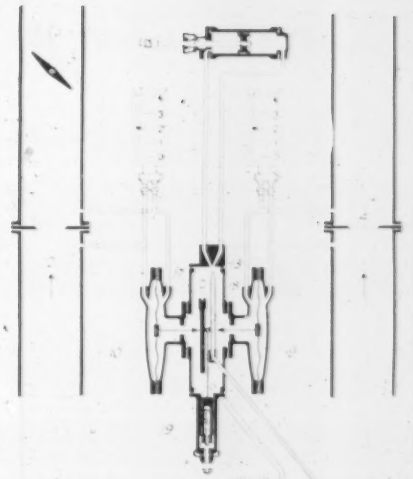


Fig. 22. Askania proportional flow controller. An increase in "governing" flow through orifice 4 produces higher differential on diaphragm 9, moving it and jet pipe 15 to the left, raising pressure in left end of power cylinder 16, and opening valve 3 further. The resulting increase of "controlled" flow through orifice 5 increases differential across diaphragm 10, moving it to the right and returning jet pipe 15 to the equilibrium position. Adjustment of ratio is accomplished by moving slider 18 backward or forward between jet pipe 15 and arm 17. Since these two arms are pivoted at opposite ends, the obvious effect of shifting slider 18, which is the action link between the two arms, is to change the loading ratio between diaphragms 9 and 10.

therefore, to systems embodying *fluid meters*.

FLUID QUANTITY CONTROL

The old inaccurate "fillers" are giving way to equipment using positive meters, the counters of which actuate improved cut-offs. A recent development is flow control with positive primary, as exemplified by Askania's centrifugal tachometer mechanism driven by a quantity meter and commanding the controlled valve. There is also a trend toward using positive meters for ratio control on an exact volumetric basis, two meters being geared to each other by means of a variable-speed positive drive.

FLUID RATE CONTROL

Flow-rate control engineering, although today still far from being generally understood, at least has been developed vastly further in the last ten or fifteen years than in the previous quarter-century.

A word about H. C. Smoot's contributions to this field may not be amiss; this brilliant inventor was apparently the first to recognize that sensitivity, power, speed and stability were essential factors in design, not to be guessed, but mathematically calculable. His work influenced the design of all types, even for some years after his death.

Time and space permit only mentioning a few recent designs without attempting to pass on their merits.

Simplex and Builders, before the last decade began, had been making control systems for waterworks, filtration and sewage, and these in the main have not been changed. Builders added the Chronoflo transmission to the controller operation, permitting long-distance remote control. International Filter brought out a new system, small and self-contained; requiring no auxiliary power supply.

Numerous other companies entered the field. Perhaps the most important tendencies are: (1) ratio control, (2) positive positioning of valves, (3) anti-hunting devices.

American Meter brought out a constant flow controller which employs their usual differential recorder mechanism to operate a rotary valve admitting compressed air to, or exhausting it from, the diaphragm motor controlled valve. For the proportional control of two fluids they introduced the mechanism shown in Fig. 20.

Askania developed a number of controllers employing their jet pipe and power cylinder system. Their jet pipe principle is shown in Fig. 21; one of their ratio controllers is shown in Fig. 22.

Taylor and Foxboro entered the field of flow rate control with their respective air-operated systems. Both brought out positive valve positioning devices.

Tagliabue also continued to rely on air operated diaphragm valves. To obtain greater stability than is afforded by the usual pneumatic system they brought out the Damplifier System, Fig. 23.

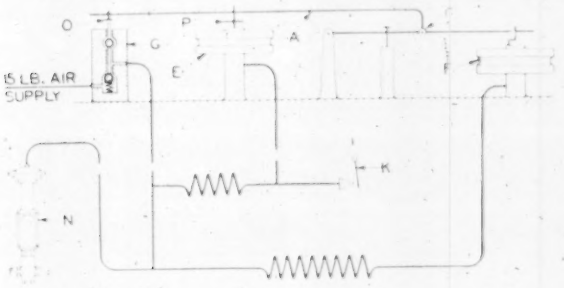
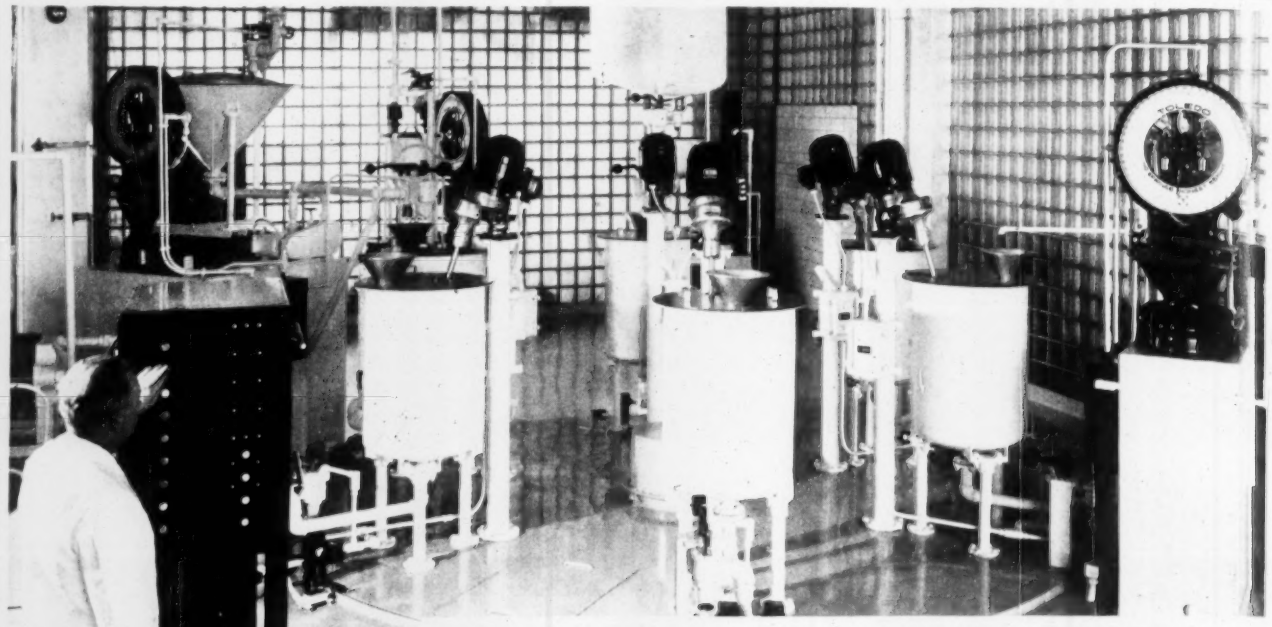
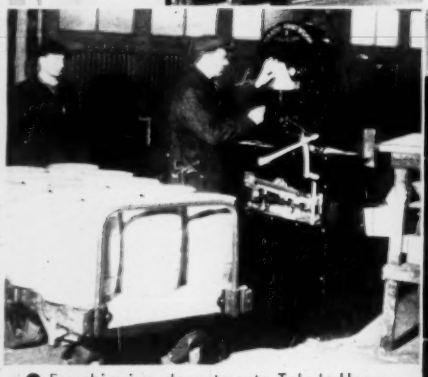


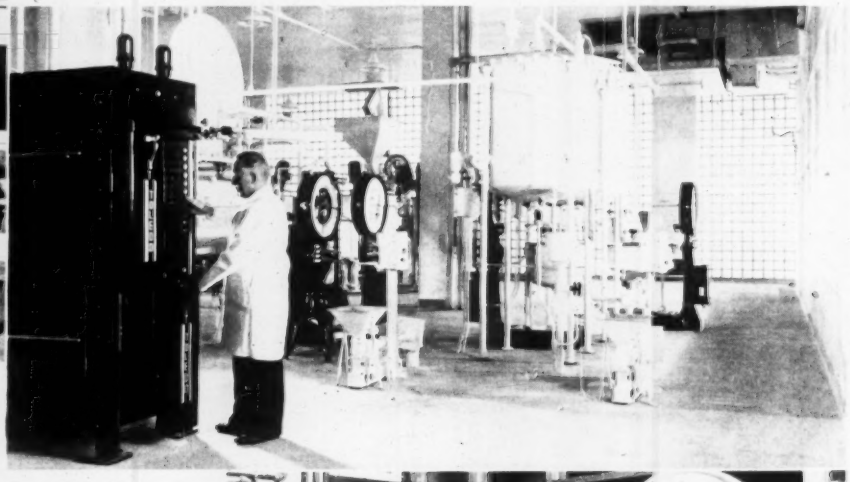
Fig. 23. Tagliabue "Damplifier" control. Flapper valve K, rotated by the arm of a differential gage or other flow-responsive device, toward or away from an air nozzle, forms the primary pilot. A 15-lb. air supply is maintained on ball valve G. Assume a decrease in flow from equilibrium subsisting. Flapper K rotates toward the nozzle, decreasing air escape, and rapidly increasing pressure in capsule E, which raises lever A upward causing ball valve G to decrease pressure to the diaphragm on control valve N. This decreased pressure now reacts on capsule F through the small viscous restriction (shown like an electrical resistance) and F starts to collapse again, while only a small change in N has taken place. Now capsule F collapses still more slowly, on account of the larger viscous resistance and nearly restores the function of G, through fulcrum points C and P. Meanwhile valve N is still opening, and the flow arm operated from a differential gage connected with an orifice in the line controlled by valve N, now has moved K back near its former position. Equilibrium is re-established when the flow as indicated by K is again at the control value. The net effect is a quick impulse to correct a change, followed by a decreasing rate of change as the control point is approached. The intent is to damp hunting.

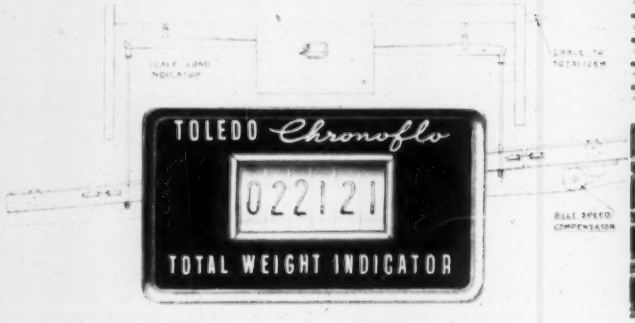


● In the Campana Company's new plant, glass-lined tanks, each with its own agitator, are mounted on a revolving table. At each indexed position materials are automatically discharged into the tanks by Toledo Scales equipped with photo-electric cut-offs. A Toledo Master Control Panel controls the entire batching and mixing operation.

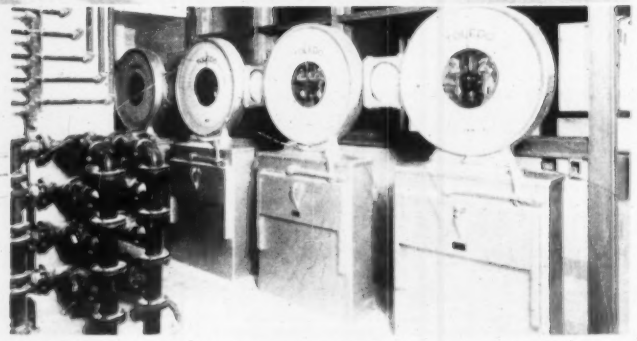


● For shipping departments, Toledo Heavy-Duty Floor Scales equipped with Printweigh produce indisputably accurate printed-weight records.





● There is wide spread interest in the new Toledo Chronoflo Totalizing Scale. This "flow-meter for dry materials," provides highly accurate total-weight figures on materials transported on belt-conveyors.



● One of many Toledo installations in filtration plants. Chlorine cylinders are placed on the scale platforms. Graphic-recorders produce a continuous record of the discharge of chlorine.

The past decade has seen sweeping advances in accurate weight-control. Today scales control the accuracy of batching, filling, and proportioning; they determine unit count of individual pieces; they originate basic accounting-data. Through remote-indication they provide centralized-control. Toledo Scales cover the full range of modern weight-control requirements.

TOLEDO SCALE COMPANY · Toledo, Ohio

A DECADE *of* PROGRESS *in*

Weighing and Proportioning

of Solid & Granular Materials

By M. G. MASTIN

Chief Chemist, Newark (Calif.) Plant,
Westvaco Chlorine Products Corp.

OF recent years, cost accountants and plant managers have shown an increasing interest in the accuracy of their plant records, especially in regard to the flow of their various materials. This insistant demand for better and more accurate means of measurement has stimulated a more rapid development of weighing equipment during the past decade than during any like period in the past. As a result, we now have available a vast array of feeders, weighing conveyors, automatic scales and packaging machines from which to choose a device for almost any weighing purpose. Controlled flow, by weight, and automatic proportioning, have not only in large measure eliminated the human element but made possible better products at lower costs.

So many new devices, and improvements on old ones, are now on the market that a large book would be required to describe them fully. This brief article can cover only the most outstanding developments.

Purely structural improvements are many and varied. Among these can be mentioned new alloys for knife edges and other structural features, corrosion resistant finishes, built in temperature correction, dust tight housings, replaceable knife edges, speed of weighing, elimination of leveling devices, avoidance of parallax in reading, and improved legibility of figures.

The old-fashioned counter scale and platform scale are still largely used, and are reasonably accurate and dependable. The graduated beam, however, is fairly difficult to read accurately and unless the operator is alert mistakes can easily be made. A number of devices have been perfected for attachment to a beam scale, embodying a pointer which has a much larger range of travel per unit of weight than has the beam. When first introduced, one inch of travel per ounce was provided for, but the demand for accuracy has been such that more sensitive readings are now available. The use of this idea of over- and under-weight indication has not been confined, of course, to the above use, as a complete line of scales has been devised using this principle. In predetermined weighing, small overweight losses can thus be eliminated and at the same time underweight is insured against. Still greater sensitivity has been obtained by projecting the shadow of a line on a ground glass plate. By this means, a movement of $\frac{1}{8}$" of beam travel can be magnified to 4" of pointer (shadow) travel.

To procure greater readability of the beam scales, manufacturers have developed the type of scale that has a pointer moving over a chart of figures in such a way that the exact weight can be read off at a glance. Scales for weighing all sorts of specialty products and with many degrees of sensitivity now employ this scheme. The so called computing scales belong in this classification.

Dial scales, while older than this decade, were also developed with the object of better readability. Of recent years, the manufacturers of dial scales have paid increasing attention to the development of great sensitivity in low-capacity scales, and ruggedness and accuracy in the huge thirty- and forty-ton truck scales. In addition, and still with the object of greater accuracy, they have added the printed weight ticket feature in several forms. Either inserted printed forms or strip charts can be used and, in addition, a selective numbering keyboard can be provided by means of which the operator can place indentifying records on the ticket at the time the weight is printed.

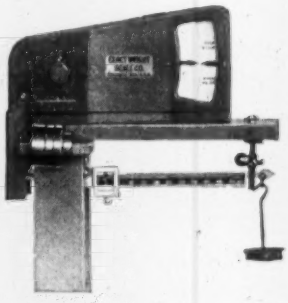
Remote indicating heads are now available for dial scales, which can be mounted in an office distant from the scales. This enables the management to know instantly and continuously what is going on in the various departments where weighing is done, and of course adds to the general accuracy of the figures obtained.

Batching scales of many types and for many purposes are now in use. One of the most ingenious developments is the application of the photoelectric cell to weight control. Scales can now be bought with this control built in, or the control can be purchased as an attachment to fit any dial scale. The "eye" is so placed that when the pointer passes over the predetermined weight, it cuts off the beam and a relay is operated cutting off the flow of material to the scale. For greater accuracy, a second cell is used for complete cut off, the first being used to operate the "dribble." The ingredients of the batch may be weighed and discharged individually; or a complete batch of as many as twelve ingredients may be accumulated on the scale, thus providing a check on the weight of the complete batch before it is discharged. The apparatus may be arranged so that it is completely continuous and automatic, stopping only when the button is pushed; or it can be semi-automatic, the operator pushing a button to start each weighing operation or cycle of operations.

Automatic bagging scales of many styles are available. These may consist of a pivoted hopper which drops slightly when loaded to a predetermined weight. This slight movement actuates devices which cut off the stream of material to the hopper and at the same time discharge the contents of the hopper to a bag or other container below. Or the bag itself may be the hopper, it being carried either in a cradle or hung by the mouth to the scale. In this case, only one cut-off gate is necessary. Thousands of machines using this principle fill valve bags with portland cement, lime, plaster, etc., and other ground products.

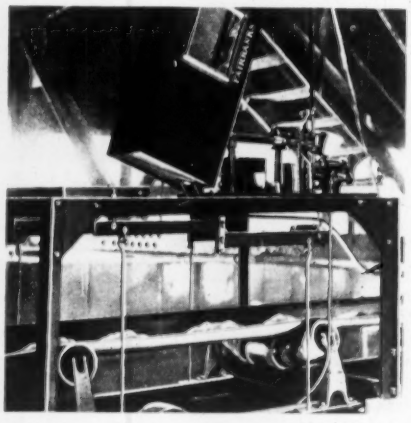
This balanced hopper idea has been developed for many special uses. A western manufacturer has built a machine that fills ninety two 1-lb. coffee cans per minute with an accuracy of $\frac{1}{16}$ oz. per can. The machine has two hoppers that fill and discharge alternately. Each hopper has its own inlet and discharge gates operated by solenoids which in turn are energized through mercury switches. Another manufacturer makes automatic scales for weighing sugar beets to the cossette cutters at a rate of 3000 lbs. every forty seconds. When the hopper drops, the feed gate is closed, and a motor operates a sliding weight on a secondary beam until the beets which were still in the air when the gate closed are counterbalanced. This beam then tilts, the motor stops, the secondary weight is retracted, the weight is printed on a strip chart and then added to the previous total, the hopper discharges its contents and returns to position thus starting a new cycle. By the addition of a timing device, such

machines become controlled weight feeders. One such scheme employs a shaft revolving at exactly one revolution per minute and carrying wheels with two, four, and six contact studs. If the two stud wheel is selected, two contacts and thus two dumps of the hopper are obtained per minute. The hopper carries a scale beam by means of which a predetermined amount of material causes the hopper to drop, empty, and return to position. The feed gate does not open until the next stud makes contact. Another modification of the same device produces a machine which weighs a variable flow of material, as for example, the discharge from a rotary kiln. In this case the hopper fills as rapidly as the flow of material permits, until it reaches its predetermined capacity. It then drops, closing the feed gate, and operates a counter or records on a chart.



Right—Jeffrey Mfg. Co.'s "Waytrol" conveyor scale system.

Below — Weighing mechanism of a continuous-weighing system with electrical remote-recording instruments (Fairbanks, Morse & Co.).



Feeders of dry materials, unless they employ actual means for weighing, usually are simply volumetric feeders. They therefore depend on constancy of bulk density for their accuracy. Plate, rotating disk, screw, bucket, and belt feeders are old and well-known. The past decade has seen as a new principle the application of the vibration produced by an electromagnet to a trough. The trough, usually horizontal, is placed under the bin spout, and with no current there is no flow. By varying the intensity of the current or the amount of metal in the magnetic field or the position of the trough with relation to the bin spout, the flow of material can be anything from a dribble to the full capacity of the trough. Such feeders work best on dry, granular materials that flow without packing. A recent modification of this feeder receives the material from the trough on a short belt conveyor which is carried on a scale. If it is only desired to know how much is flowing, the scale record gives this information. If constancy of feed is desired, the scale mechanism operates a device which continually corrects the magnetic intensity of the vibratory feeder to keep the weight of material on the conveyor belt constant. For smaller flows the trough feeds a hopper on a scale, which when filled to a predetermined weight cuts off the vibrator. An electric timer gives one, two, or four dumps per minute.

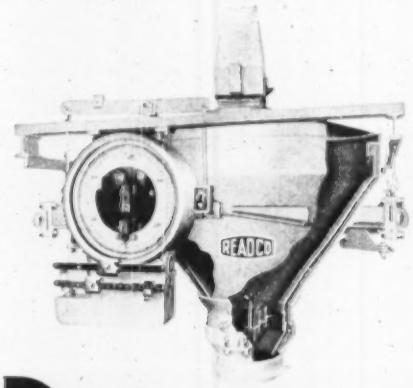
Any of the simple volumetric feeders become weighing conveyors when a similar scheme is adopted, *i.e.*, delivering to short belt conveyor on a scale mechanism which makes a continuous record of the amount of material passing. One make of weighing feeder is a short, tilting belt conveyor carrying a counterbalancing arm on which a predetermined weight may be set. Variations in amount of material carried cause the conveyor to tilt either up or down, causing a gate to open or close slightly, thus adjusting the flow to the required amount.

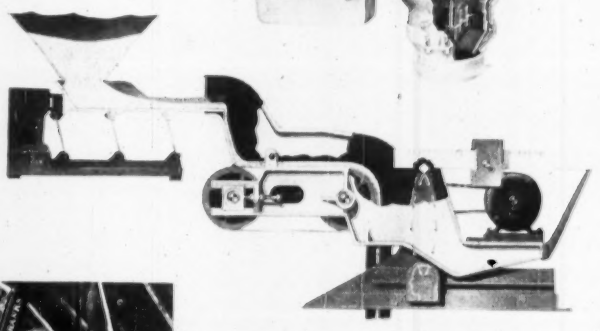
Several types of weighing conveyors (or conveying scales) employ the method of weighing the material carried on a belt conveyor. In some, the belt passes through the machine, the carrying run being supported by troughing rolls mounted on the scale mechanism. In others, the machine is itself a conveyor, a section of the belt and contents being weighed continually. Various ingenious schemes are used for recording the weight of material passing or for controlling the amount. The simpler machines indicate the instantaneous loading only. Others indicate, record, and integrate. At least one machine includes the speed of belt travel in its calculations, thus overcoming any inaccuracies due to voltage or cycle variations. All these machines go to great lengths to avoid friction or other damping of their weighing mechanisms. Some do this mechanically and some electrically. Perhaps the best effort in this direction is shown by the inventor who mounts a light source near his scale beam; and by means of mirrors projects a black line, indicating per cent of loading, on a scale at one end of the instrument casing. The same machine also records electrically at any distance. Where a belt conveyor would not be suitable, because of temperature or other conditions, pan, apron, and bucket conveyors are used. One such machine, for hot or abrasive loose materials, embodies two short, tilted conveyors, one of which feeds the other mounted on a scale. When the correct amount of material is carried by the weighing conveyor, the mechanism stops the feeder conveyor, thus shutting off the supply. The weighing conveyor continues to run until discharged when the feeder conveyor again starts up.

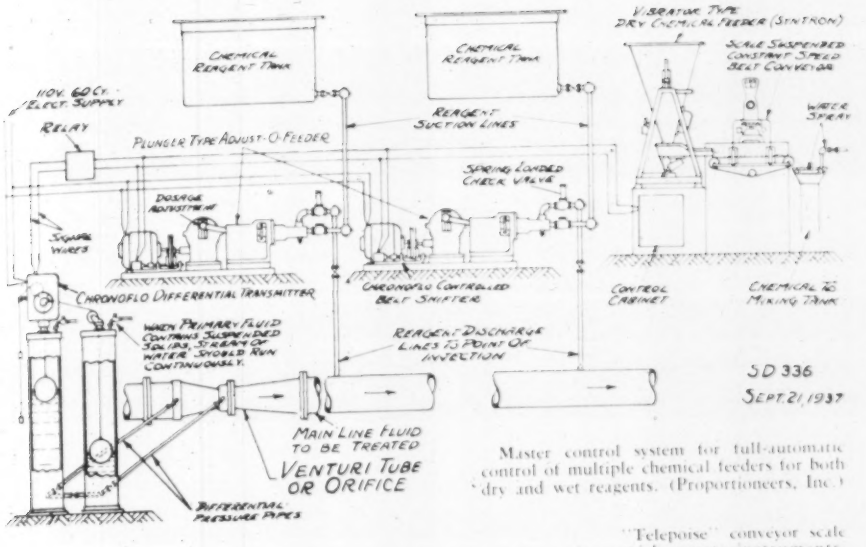
Extreme left — The Howe Illuminated Weightograph attachment for increasing the ease of reading a scale.

Left—Exact Weight Scale Co.'s magnifying "over-and-under" device for attachment to scales.

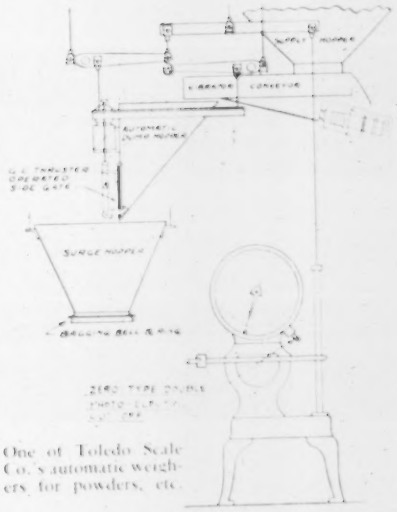
Upper right — Read Machinery Co.'s dustless weighing hopper.



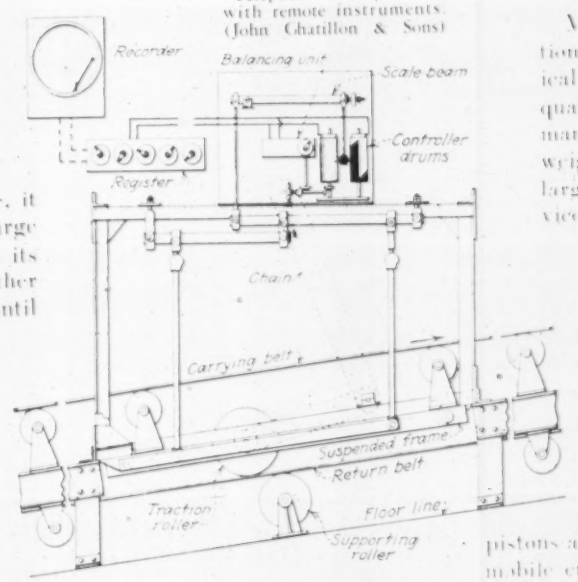




Master control system for full-automatic control of multiple chemical feeders for both dry and wet reagents. (Proportioneers, Inc.)



One of Toledo Scale Co.'s automatic weighers for powders, etc.



"Teleposer" conveyor scale with remote instruments. (John Chatillon & Sons)

Any of the above types of conveyor scales become proportioning scales when two or more units are electrically interlocked in such a way that known and predetermined weights of materials are discharged at equal intervals. When this is done, it is usual for each unit to weigh its charge and close its portion of a circuit as its hopper or scale beam tilts, or by other suitable means; no unit discharging until all have thus made the proper signal, when all discharge together. An obvious advantage of such a system is that a given mixture will always be exactly proportioned, because should the supply of any ingredient give out, the unit supplying that material will fail to operate and will prevent all the others from discharging their contents until the deficiency is made up. Signal lights or alarms notify the operator which material is lacking. Such systems include apparatus for the continuous recording and totalizing of the flows of the several ingredients so that a complete record is available for the accounting department.

When flows of solids must be adjusted and proportioned to a liquid flow, the solution of the problem is somewhat different. One successful system employs a Venturi tube or an orifice in the main fluid line. Variations of flow produce variations in liquid level in float pipes connected to the pressure taps. Suitable floats operate an electrical transmitter which sends out time signals and thus the flow of solids is proportional to the flow of fluids. Several solid feeders may be operated by one fluid flow, and in addition, suitable pumps can add fluid reagents simultaneously. The amount of material fed by each feeder can be adjusted individually through wide ranges and as desired.

Another scheme uses a displacement meter for measuring the main fluid flow. An electrical contact in the meter register closes a circuit each time a definite quantity of fluid has been passed, operating a suitable dry feeder for a definite time interval through time delay relay. In this manner predetermined amounts of solids are fed proportionally to a fluid flow of constant or varying rate. These systems are made to indicate and record totals when desired.

Modern high-speed production has necessitated mechanical methods of checking the quality of the products. In many cases this can be done by weighing, and as a result a large number of ingenious devices have been developed to meet special needs. Sorting of packages by weight is now commonplace. Such machines easily detect the absence of a single unit in a shipping carton, for example, and automatically push the underweight carton to one side for inspection. Classifying pistons and connecting rods for automobile engines is done by other machines. The weight per square foot or thickness of such materials as paper, roofing, felt, tire tread, and auto top material is checked continuously and recorded by other machines. This is done while the material is in motion and without cutting stock for samples.

It is believed that one of the principal reasons for the success of many of the modern devices for the weighing and proportioning of solid materials in transit has been the enormous amount of study which has been given to the properties of the materials to be handled. Hardly any two materials have identical flowing properties. Granular materials usually flow easily, but may tend to classify with consequent variation in bulk density and other properties. Finely divided substances are prone to "arch" in bins and "flood" or flow like water if slightly aerated. Some materials pack readily and must be kept aerated, while other are sticky and do not move forward cleanly. Dusty materials, abrasive materials, hot materials, corrosive materials—all must be handled, weighed, proportioned accurately. Until a substance can be "handled" successfully it cannot be weighed successfully with automatic equipment; and almost every application presents different problems, each of which must be solved before success is attained. Great credit is due those individuals and firms whose inventive genius and persistence have given us so many useful types of equipment; and it is hoped that our progress along these lines will be as great in the future as it has been in the past.

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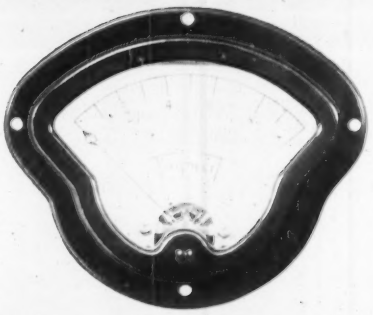
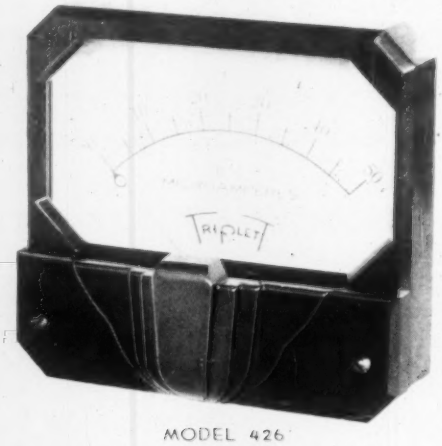


MODEL 529



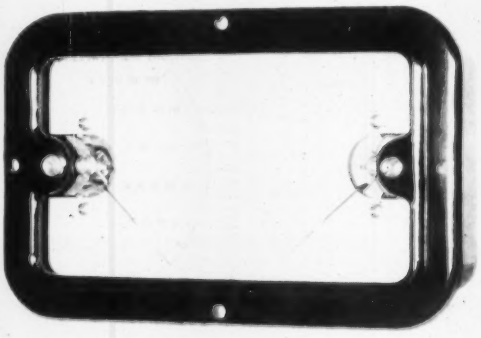
MODEL 426

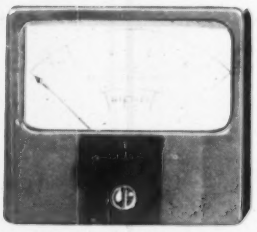
Model 426 4" instrument with Front illumination attachment. A beautiful new design. Mounting screws concealed.

Model 521 (Model 321-3; Model 221-2) a 5" Round design for flush mounting. Also available in projection mounting and with mirror scale and knife edge pointer.

Twin Instrument Exclusive Triplett Design. Two separate instruments in a single case. 3" movements. Furnished in any combination of A.C. or D.C.

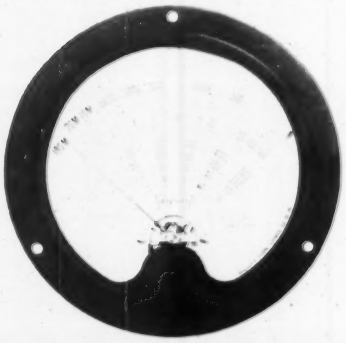
TWIN INSTRUMENT



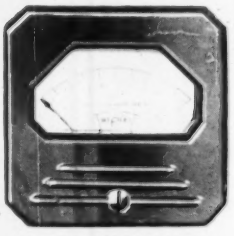


MODEL 326-A

Model 326-A—3" instrument. A new design for projection mounting where necessary to conserve space.



MODEL 521



MODEL 227

Model 227 (Model 327-3) 2" instrument for flush mounting. Molded Case.

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A DECADE *of* PROGRESS *in*
Electrical Instrumentation

By E. S. LINCOLN
Consulting Electrical Engineer, New York

MORE than twenty three hundred new instrumentation devices were described in the "New Instruments" columns of *Instruments* since the first issue. Of this number, more than fourteen hundred are electrical. Obviously it would be difficult to review them all, even if space permitted. However, the majority of new instruments and accessories are not those used for the measurement of electrical magnitudes but for many other measurements, using electricity as a means. Moreover, instruments which a few years ago were confined to the laboratory, in the hands of scientists, are now in every-day use in plants. Examples are the galvanometer, potentiometer, Wheatstone bridge and their multiform industrial adaptations. Let us start with a broad survey, by analyzing the totals of the instruments, controls, and accessories described in "New Instruments" in each year of the last decade.

	'28	'29	'30	'31	'32	'33	'34	'35	'36	'37
Total devices	81	96	134	237	281	301	311	300	311	311
Using electricity as a means	28	54	75	129	172	194	176	180	205	215

Twenty eight new electrical devices and instruments in 1928; two hundred and fifteen in 1937: this is important. One third electrical in 1928; two thirds electrical in 1937: this is not only important but highly significant. Truly, the electrical instrument manufacturing industry has been increasingly active! Truly, there is a definite trend toward electrifying the instrumentation of *all* industries!

During the last decade we have lost three great leaders who pioneered the basic electrical instrument industry of America: Professor William H. Bristol in 1930; Dr. Edward Weston in 1936 and Professor Elihu Thomson in 1937. Most electrical instruments in use today embody results of their basic inventions or developments of fundamental principles.

It is quite fitting, before attempting a review of the industrial instrument developments, to pay a tribute also to the living scientists, of whom those at the National Bureau of Standards do much toward better measurements. I shall mention only a few of the activities of the Bureau during the past decade:

For some time the Bureau has had under construction a large absolute electrometer. This has now been completed and accurate alternating current voltage measurements may be made up to 275 kv. So far this electrometer has been used up to 100 kv. to check the correctness of practical methods generally used for precise measurements of high voltage. The results have been gratifying and have checked within a few hundredths of 1%. This device is the world's largest precise absolute electrometer.

The Bureau has also extended its range for the testing of current transformers to a maximum of 12,000 amp. The subject of current transformer ratio and phase angle differences has been further studied, together with variations of the position of the primary return lead and variations of the primary current from the sine wave form. The results of this work have been published by the Bureau.

The Bureau has also developed a special potentiometer for the direct indication of small temperature differences.

The Bureau is doing some extensive research work in connection with resistance standards and has developed a new form which has maintained its exact value after shipment to other national laboratories. Previous resistances have, for some unknown reason, shown changes in values after shipment has been made. Considerable work has also been done in connection with standard cells and those now in use have proved superior to those previously used. A special potentiometer known as the "Standard Cell Comparator" was designed for the inter-comparison of (unsaturated) standard cells. This potentiometer was built in connection with an investigation of temperature inequalities of the e.m.f. of commercial standard cells.

A study showed that the relatively large and heavy copper pots previously used by the Bureau are not as effective in maintaining the necessary temperature equality throughout the cell as the relatively thin copper lining now used within the Bakelite case of the cell.

The Bureau has also made some extensive temperature compensation investigations in connection with shunted millivoltmeters (ammeters) and of volt millivoltmeters which perform the function of a voltmeter or millivoltmeter as desired. Special work has also been done in connection with variable self and mutual inductors. Two general theorems for maximum efficiency have been derived and their correctness verified by the construction of an inductor by the Bureau.

Outside of electronic applications, no new fundamental principles have been used, but the potentiometer and Wheatstone bridge principles have been utilized as methods of precise control. Improvements in alloys have produced better springs, magnetic steels, fans, shields, etc. Other materials such as plastics and non-glare glass, have made possible a better finished instrument, increasing reliability, endurance and accuracy.

LABORATORY STANDARDS

The so-called laboratory or secondary instruments have undergone a few refinements, increasing their ability to maintain correct calibration. Spring fatigue has been reduced and zero stability has been improved.

PORTABLE INSTRUMENTS

All lines of portable ammeters, voltmeters and wattmeters have undergone refinements for greater accuracy and ruggedness. The tendency has been to decrease the size of these instruments and also to increase the number of ranges in the more common types of ammeters and voltmeters. In some instances, as many as fifteen ranges are combined in one instrument. New instruments have been developed for measuring extremely low values of both current and voltage to meet the demands of investigators in all branches of the electrical, and in many other industries. This has led to more sensitive types of microammeters and millivoltmeters, which are now common everyday instruments, whereas, a few years ago they were considered quite special. The small size portable electrodynamometer instruments have received considerable attention due to their accuracy, flexibility and lower price range.

Both the thermocouple instruments and those using the copper-oxide rectifier have met the demand for accuracy and range for measurements on high frequency or low voltage a.c. circuits. With the copper-oxide rectifier a delicate permanent-magnet moving coil voltmeter may be used on a.c. circuits for measuring extremely small values not possible on other types. Such a combination requires extremely low current consumption from the circuit under test and is available for voltage

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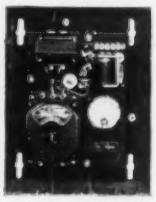
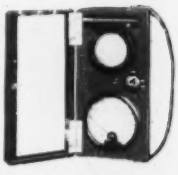


✓ **Illumination Meters and Controllers**—Foot-candle meters . . . the standard instruments for illumination level tests in industry and the home. Special high-sensitivity instruments for photometric research . . . Photronic Controllers which turn lights on and off at predetermined levels.



✓ **Photometric Potentiometer and Control Unit**—The latest step in high-speed, high-sensitivity control . . . provides positive operation of recorders and relay controls.

WHETHER your needs arise in the field of photometry, of modern industrial control, or in some special field where light must be converted to an electrical response, it will pay you to check with WESTON.

Thanks to the WESTON Photronic Cell, illumination levels have become understandable to the public, and light beams have become serviceable to industry. Today, this same cell is the basic element for an increasing number of Photronic-powered units for measurement and control . . . units engineered by WESTON to expand the practical usefulness of the photoelectric effect.

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In any event, the same WESTON engineers who have brought the usefulness of Photronic equipment to its present point are still at your service. Their counsel may bring to light new possibilities; it may keep you from duplicating old errors. Simple or complex, if there is a photoelectric solution to the problem you have in mind, WESTON can help you solve it. Weston Electrical Instrument Corporation, 591 Frelinghuysen Avenue, Newark, New Jersey.

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WESTON *Instruments*

scales of three or four volts for full scales values and from 0.5 to 0.20 milliamperes.

Due to the increased use of condensers, especially in the radio field, "capacity meters" have received considerable attention and are now available in a large assortment of ranges. The "Megger" capacity meter is a fairly recent development, permitting measurements to be made without an external source of current—this instrument being entirely self-contained, as is the well known Megger used for resistance measurements.

Several new types of "Meggers" and megohmmeters have appeared, all of which show a trend toward compactness in size and lightness in weight, and ranges have been considerably extended. These types of instruments thus cover practically the entire range of resistance measurements required by the electrical industry.

Of new instrument developments, undoubtedly the so-called foot-candle or light meter has been most universally used. It consists of a photoelectric cell mounted in combination with a sensitive magnetic moving coil millivoltmeter. It is used for determining the amount of light available. The voltage produced by the cell is directly proportional to the amount of light that shines on the surface. The millivoltmeter has its scale calibrated to read in light values or intensities for proper reading.

Electrostatic voltmeters have undergone improvements and have also been reduced in size. These instruments are independent of frequency, wave form and temperature and may be used on either a-c. or d-c. circuits. The small sizes have a 3 1/2" dial and may be used for measurements up to 3500 volts.

The vacuum tube voltmeter has made its appearance. It is self-calibrating and its stability in giving accurate readings is assured. It is designed for measuring low a-c. and d-c. peak voltages without consuming current. For measuring potentials in radio and audio frequency circuits this voltmeter may be used. It is adapted for measurements where the high resistance moving coil instruments would introduce distortion.

A high-voltage, high-frequency voltmeter of the capacitance potentiometer type has been developed, having a direct reading scale over a frequency range of 20 to 100 kc. and calibrated from 10 to 50 kv.

For checking connections of polyphase circuits for motors, relays, etc., where the phase relation of the circuit must be known, portable phase indicators have been developed. These instruments are convenient for use by service departments.

Self contained portable testing sets have received considerable attention and have been well reivd by industry inasmuch as they save a great deal of time and may be operated by those not thoroughly familiar with complicated instrument connections. A good example is in the "Industrial Analyzer" which is a combination of several small size indicating instruments all contained in one case for making complete measurements on power circuits. With these sets, the operator may determine the total load of a circuit and measure its component amperes, volts, watts and power factor. All internal connections between the various instruments are provided in the set, which greatly reduces the time and thought required in making instrument connections. Similar sets containing miniature instruments have been used extensively in the radio field for testing tubes, etc. Combinations of this type are complete with properly marked binding posts for external connections, together with the necessary switches and controlling rheostats. For the automotive industry a test set has been developed which simultaneously tests all three cells of the ordinary six-volt storage battery. This set indicates the actual voltage of the battery, within 2%, with a discharge rate as high as 300 amperes. The voltmeter is so arranged that it may indicate the voltage of each individual cell under discharge conditions.

Instruments are being mounted directly upon many industrial machines, while others are arranged for intermittent use. The latter are known as the "Plug in" type and have connections so arranged that they may be "plugged" into the circuit directly upon the machine and removed when readings have been taken.

SWITCHBOARD INSTRUMENTS

Switchboard instruments have received their share of improvements in accuracy and reliability with the tendency for smaller sizes still existing. A-c. and d-c. rectangular indicators measuring 3" square are available for either flush or surface mounting. Ammeters containing three separate movements have been combined in one case so as to save space. A number of switchboard instruments have been provided with contacts for alarm purpose, especially in connection with overload devices, etc.

The practically universal use of electric clocks has made it necessary for public utilities to maintain an exact frequency upon their systems. This in turn has called for frequency meters of high accuracy and also with longer scales which may be easily read from a distance. To meet this demand, switchboard frequency meters have been developed with a full-scale reading of one cycle having the basic fixed frequency value placed at mid-scale. Such instruments give a large deflection whenever the frequency increases or decreases a fraction of a cycle from normal.

RECORDING INSTRUMENTS

Recording (or "graphic") instruments of all types have seen many improvements and refinements: better pens for making a smoother chart, larger scales and portable instruments that are much lighter in weight than those previously used. The Telechron clock is being used extensively to replace spring-wound movements, and spring-wound movements are now electrically wound. Recorders may also be obtained with two and three pens for making simultaneous readings of voltage on two or three circuits.

New types of recorders have appeared, some of which are used for electrical measurements, such as the kva. meter and the combined frequency and time recording instrument. This instrument contains one chart which shows both the frequency of the circuit and the accumulated error between system time and standard time. Records of speeds may also be made with systems using the conventional magneto and recording voltmeter, distance between the two being of little concern.

The photoelectric cell has been applied to recording instruments. In such instruments the moving element uses a light beam for a pointer and therefore the instrument can be made lighter and less rugged, making the instrument more sensitive. The mechanism of the instrument is capable of exerting any necessary amount of power for recording or controlling purposes without in any way burdening the measuring element. No matter how delicate the sensitive moving element may be, it can operate a powerful control, if desired. In one such instrument the light beam is reflected from the moving element and the motion of this light beam is followed up and recorded by a photoelectric cell arrangement; the tangible pointer is then clamped for an instant, and, while clamped, depressed against a type ribbon below

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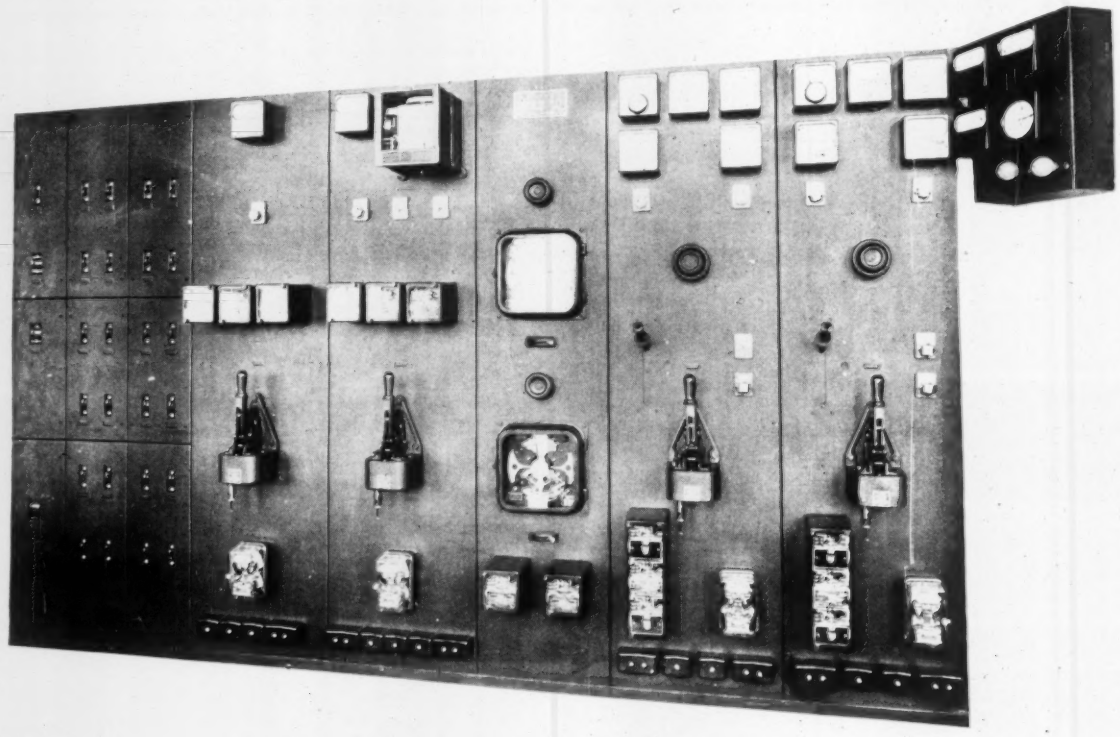

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which travels a paper chart upon which is left an imprint when the ribbon is struck by depressing the pointer. This is a radical departure from present practice and may be used to measure temperatures, speeds, pressures, etc.

Recording instruments have been made available in flush types for panel mounting.

METERS

Watthour meters have received their share of improvements for accuracy and ruggedness and have reached a high state of perfection in recent years. The so called "plug-in" detachable or socket type has made its appearance, making it possible to quickly remove a meter from service for test purposes and replace it with another without making the usual connections. Demand attachments have been applied to watthour meters to show the maximum demand that has occurred on the system in which the meter is connected. Watthour meters have been provided with indicating attachments for determining the maximum kw. demand of the circuit for a definite period. Such indicators when reset destroy any record for future comparison. To offset this condition, several meters have been developed in which a record is retained and available for future reference. Watthour meters have been combined also with recording wattmeters, and this combination gives a chart record of the kilowatt hour constant, together with the load on the system and the time in which changes take place.

To meet the demands of some public utilities having somewhat complicated structures, the Kva. Demand Meter has been developed. One such meter records eight different factors relating to the circuit upon which it is connected, including both the kva. and kw. demands, the maximum kw. demand and the power factor at the time of the demand, the time that the demand occurred, the reactive component demand, the energy component in kilowatt hours and also reactive component in reactive kilovolt ampere-hours. To say the least, this is a comprehensive instrument.

For metering and controlling domestic loads, including off peak water heating, a watthour meter combined with a time switch has been made available. During certain pre-determined periods the time switch disconnects the water heater.

Time switches combined with watthour meters are used also to shift the reading from the regular dial to an auxiliary dial where two rates are in effect during different hours of the day. It is now possible to measure, with a much higher degree of accuracy, kilowatt-hours in a single self-contained meter, using a single disk on a three-phase four-wire system by using three current coils and two potential coils.

RESEARCH INSTRUMENTS

Research workers and laboratory workers now have at their command a large number of scientific instruments and special instruments. Refinements have been made in capacitance and conductance bridges with which precise measurements may be quickly made for capacitance and power factor of dielectrics.

The potentiometer, which until recently has been considered a highly specialized laboratory instrument, has gone through many refinements. These refinements have simplified their operation by reducing the amount of switching necessary. Standard cells have also been self contained or have been placed within the instrument proper and accuracies have been somewhat increased. Instruments for the measurement of magnetic properties have received considerable attention and are now available for general use, one of these being the so-called flux meter.

While not a direct reading measuring instrument, a device has been developed for detecting the presence of magnetic material in asbestos, glass, sand, mica and other similar materials and measuring their amount.

A new magnetizing device has been developed for inspecting tools and heat treated parts, making it possible to locate quenching cracks, grinding checks and seams, rendering them visible when they cannot otherwise be seen. Another device, known as the "Magnetic Inspector," is used for checking the physical properties, thermal history and chemical analyses of magetic materials and of parts. Coils can be checked for shorted turns, number of turns, inductance, grounds and opens.

It is now possible to measure the currents produced by lightning; and a series of instruments and devices have been produced for carrying out investigations of this phenomenon. Part of this equipment consists of a so called lightning bolt or crest ammeter, which may be attached to a transmission tower, making it possible to measure high frequency current, together with its polarity. Although this is not accomplished on a single instrument of the conventional types, the method makes it possible to tell what is going on in the lightning discharge circuit.

Resistance bridges have been produced in compact form, weighing as little as three pounds. These instruments are well adapted for accuracy measurements outside the laboratory. They have an accuracy of 1% and are used for measurements up to 50,000 ohms.

A large number of special instruments have been developed for the radio industry but space does not permit a review here.

VOLTAGE REGULATORS

The electromagnetic generator voltage regulator has seen many refinements and several new types have been developed. However, the greatest advance from the standpoint of simplicity and sensitivity has been obtained with the electronic regulator. This device uses the ordinary vacuum tube as the controlling device for the generator voltage. The use of the electronic tube does away with all magnetic controlling devices, together with their various mechanisms. The field current of the exciter is supplied by a rectifier which is a part of the regulator.

ACCESSORY EQUIPMENT

To keep pace with the refinements of instruments, much has been accomplished through the improvement of accessory equipment. Current and potential transformers having smaller phase angle and ratio error, with an increase in the number of ranges and smaller sizes and less weight are noticeable. The split core or cable type of combined ammeter and transformer has made current readings much simpler where the circuit cannot be disconnected.

TELEMETERING AND TOTALIZING SYSTEMS

Few of these were described in the new product department of this magazine or of any other periodical, for that matter because concise descriptions of such systems are usually impracticable. However, *Instruments* did have the unique distinction of publishing first rate descriptions of these new telemetering and totalizing systems. I refer of course to the handbook serial by Borden and Behar specifically to their comprehensive chapters, "Telemetering" and "Totalizing." These concluded so recently that they still constitute an adequate review of a decade of progress in that field.

A DECADE *of* PROGRESS *in* Machine Shop and Inspection Instrumentation

By ROBERT W. CARSON
Consultant on precision elastic elements, Little Falls, N. J.

MORE precise shop measurements and modern metal working tools, hand in hand, have been important factors in the development of our present standard of precision manufacture that has so largely contributed to improving performance and reducing the cost of products. Automobiles, radios, refrigerators, and countless other machine made products are today available at prices that would be many times higher without the precision devices developed during the past ten years.

Many of these developments have been spectacular—such as the cam shaft inspection machine developed by Ford engineers, or the Abbott profilograph that has contributed to longer ball bearing life by disclosing characteristics of finely finished surfaces; or new jig boring machines with micrometer microscopes that split "tenths" with greater ease and accuracy than thousandths were measured with the machines of 1927.

These are spectacular, but other precision devices of more common use have perhaps had even more direct influence in modern production accomplishments. Hand micrometers with hard faced anvils and spindles, such as those made by Starrett, greatly increase the life and protect the accuracy by resisting wear under constant use. Ames, Federal and Starrett dial indicators of greater sensitivity, sturdier construction and longer accuracy life have cut the cost of production inspection of interchangeable parts. Built like a watch with jeweled movements, precision cut gears and parts, the usefulness of these indicators is increased by combining them with production jigs or fixtures, or by building them into machine tools for checking the progress of machining, milling or grinding operations.

Other small hand tools and instruments have aided in obtaining the desired precision in important dimensions. Precision levels, protractors, inside calipers, gear tooth measuring tools, height gages, and other shop instruments developed or improved during the past ten years are today indispensable in meeting tolerances that are common. The Starrett gear tooth vernier caliper, for example, provides a precision means of measuring both chordal and addendum thickness of gear teeth, gear cutters, hubs, etc. Another tool simplifies the problem of laying out and measuring dovetails; cutter clearance tools check the clearance of end, side, spiral or helix angle of inserted tooth cutters. Improved instruments for measuring and inspecting springs have reduced the cost of obtaining greater uniformity. A new Coats tester combines a much wider range with more rapid operation.

Developments in optical measuring methods have made a higher degree of precision available for ordinary shop use. The tools maker's microscope, optical comparator, light wave micrometers, precision projection machines, and optical mechanical magnifying instruments, provide tool makers, machine operators and inspectors with means for controlling dimensions to ten times greater accuracy than was possible only a few years ago. Specially designed for shop use, a new Gaertner line of micrometer slides has fully enclosed steel bodies and a variety of interchangeable accessories making one microscope available for many uses. A protractor eye piece, for example, has a vernier reading directly to three minutes of arc. Special optical systems provide an erect image with natural direction of motion; precision stage screws read directly to 0.0001".

Where observation on a screen is more convenient or where magnified profiles are to be compared with drawings, the tool maker's microscope is readily converted to a projection magnifier by means of a suitable light source and special lenses; or specially designed projectors are available, such as those of Bausch & Lomb.

A recent development by Leitz simplifies magnified comparison by permitting the use of a natural size master part as a standard, eliminating large-scale drawings. Inspection of a new part and comparison with its standard thus can be made at once, work and standard being magnified together. By operating convenient knurled screws, one contour can be shifted in relation to the other for more precise determination of differences.

Optical comparators for gaging thickness or diameters of quantity produced parts have not only made possible new standards of precision, but have also reduced the cost of inspecting, sorting or selection of parts made to ordinary or fine tolerances. Most of these instruments combine mechanical and optical magnification, and for an indication provide a spot of light on a translucent screen. The Microlux comparator using this principle discloses differences as small as 0.00005" rapidly and with no dependence on the operator's sense of feel.

For conventional "go" and "no go" inspection, the Electro-Compar gage takes all strain from the operator by the use of three colored lights: red for undersize, green for oversize and a white light for correct size. Any desired tolerance ranges between 0.000,05" and 0.010" can be obtained with a positive response to within 0.000,02" all without mental effort or interpretation by the operator.

Another recent development of particular assistance in the control of metal finishes is the comparison microscope which takes two pieces to be compared and forms side-by-side images within a single field. Thus, finished metal surfaces, contours; structure of textiles or paper and fractures or flaws can be accurately compared.

Johansson precision gage blocks are today common equipment in every good tool shop; ten years ago they were available to only a few. With improved and lower cost methods of producing gage blocks, they have become the generally accepted basis for tool lay out and inspection work where the highest degree of precision is necessary. Accessories available now greatly extend their usefulness in ordinary precision shop measurements.

For still greater precision in determining size, flatness and parallelism the Van Keuren micrometer combines a precision screw and the interference fringe method of determining contact with the work. Interference bands provide sufficient sensitivity that readings may be duplicated within 0.000,01".

Photoelectric and optical methods combined have aided in measuring the condition of sharp edges. Optical magnification and electron-tube amplifiers have been combined in this development to provide a degree of sensitivity not obtainable from either method alone.

From improved hand micrometers to completely automatic inspection machines, the developments of the past ten years in measuring dimensions have had a large share in the accomplishments of modern precision production methods. But there have also been several new methods of measuring small dimensions using the electrical and electronic principles. The bridge-type electric gage, photoelectric micro-comparators and the electronic micrometer have extended the field of precision measurement by the application of equipment not available a few years ago.

Thickness of non-conducting films or surfaces (such as paint, vitreous enamel or oxide coatings) on iron and steel parts can be read directly without damaging or penetrating the surface, using the surface finish as an airgap and the steel sheet as an armature for an electromagnet in the gage head. In General Electric equipment designated for this service, variations in film thickness are shown directly on an indicating instrument.

Bridge-type measuring devices developed by General Electric for comparative measurements combine extreme sensitivity and rapid indication for inspection of finished parts. This new type of instrument is fundamentally a device by which an electric current is controlled or modulated according to the relative position of two of its parts. The relationship between current and displacement is controlled by a simple Wheatstone bridge with a pair of iron-core reactors. In two of the arms of each reactor are air gaps; in one reactor the gaps are fixed, while the displacement being measured is arranged to change the air gaps in the other core. When an alternating current of proper frequency is applied across the bridge, a sensitive a.c. instrument across the other two arms indicates any increase or decrease in either air gap. The value of this method lies in its speed and mechanical simplicity, and in its extreme sensitivity. A pointer deflection of 1" for a displacement of 0.0001" is readily obtained.

Other new methods of extreme sensitivity employ electronic means of indicating instant of contact between a precision micrometer screw and the work. With suitable electronic amplifying circuits, this type of micrometer can be made sensitive to displacements as small as a millionth of an inch. To eliminate the effect of electrostatic attraction, measurements are made with a microscopically sharp point. While not as readily adaptable to continuous or rapid inspection as some other methods, the electronic micrometer is particularly useful in making measurements where contact pressure must be avoided. It has, for example, been used extensively in inspecting springs for deflection rate, in measuring elastic drift in springs and metal bellows, in determining elastic constants, thermal coefficients bimetal sensitivity and other effects of small magnitude. [Editor's Note—Mr. Carson has pioneered in this work.]

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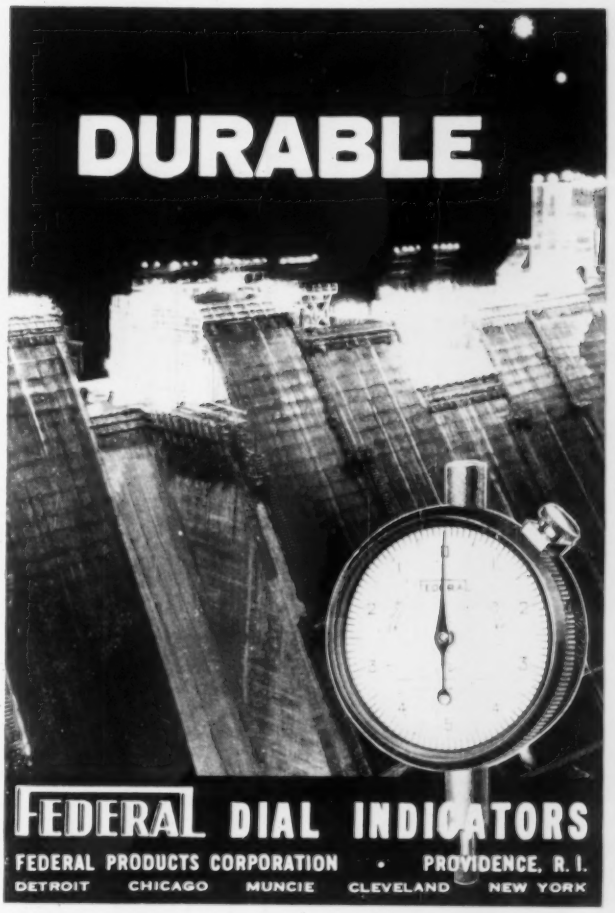
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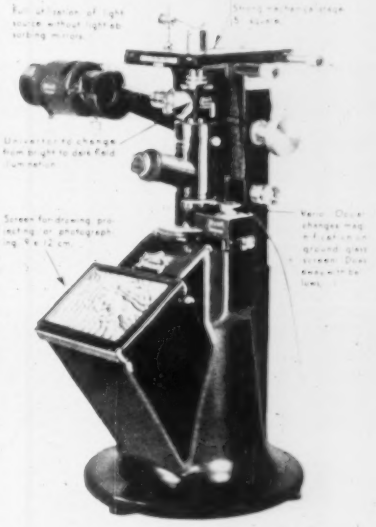

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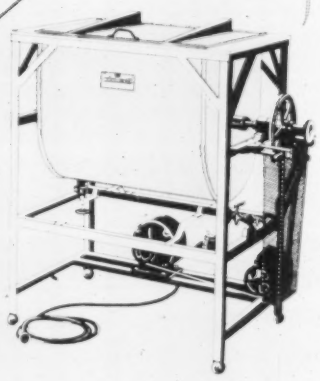

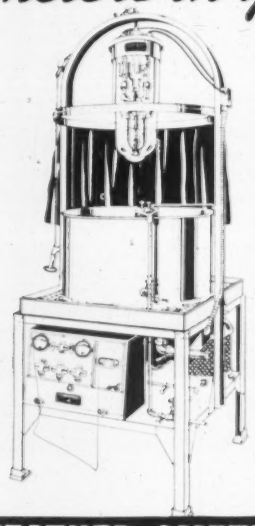

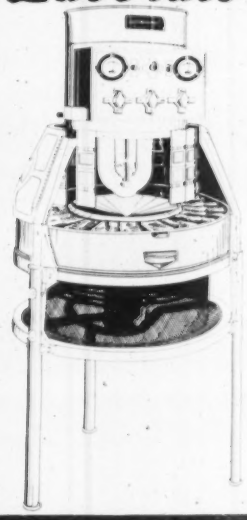

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A DECADE *of* PROGRESS *in*
Physical and Chemical Testing

By H. D. CHURCHILL
Associate Professor of Mechanics, Case School of Applied Science, Cleveland, Ohio

EVERY great river starts as a small brooklet at its source, accumulating volume and importance from its many tributaries until it becomes the mighty stream with possibilities of usefulness . . . and of danger. So it is with physical and chemical testing. From a small beginning it has now become a mighty stream, constantly enlarged by an infinite number of tributaries, capable of good or evil depending upon its use.

Not so many years ago testing was confined almost exclusively to structural elements. Today few materials and products escape physical or chemical tests during and after production or manufacture. In the last decade this expansion in testing has been enormous, so that merely to tabulate the materials tested and the test procedures would fill a large volume. There has been a continuous inflow of new materials which have required new tests or new test procedure. New uses for materials, and new concepts of the conditions under which materials work, have both required new or modified tests. The dividing line between new tests or test procedure and new applications or variations of old methods of testing is so tenuous that it is almost an impossibility to differentiate between the two. We therefore shall point out only a few of the many changes that have taken place in the past decade and attempt to show what trends may be expected in the future.

Determining the suitability of a material for use under specific conditions probably occupies the largest part of the attention of those interested in testing, and the improvement of machines and instruments in this field is of major importance. Among the oldest tests in this category are those made on the universal testing machine (tension and compression).

UNIVERSAL TESTING MACHINES

In this field, the progress in the last decade has probably been more in refinement of design rather than in new ideas. However, the new dead weight testing machine of 100,000 lbs. capacity designed and built for the Bureau of Standards is an outstanding example of an old idea built into a modern machine. Ten cast iron disks, each weighing 10,000 lbs., are so arranged that they may be placed one after the other on the specimen held by the framework of the machine.

The greater use of the hydraulic testing machine has been one of the noteworthy developments of the period and many refinements have been made, especially in the recording devices, the most recent being the new Tate-Emery dial as introduced by the Baldwin Southwark Corporation.

TORSION TESTING MACHINES

The use of the Emery hydraulic capsule marked an advance in the construction of torsion testing machines, which had long continued to be made on the old multiplying lever system or the pendulum system. In the last decade the Emmons Torsion Machine and the Sauveur Torsion Machine have been introduced. The latter is of the self indicating pendulum type with some refinements in changes and grips. The Emmons machine is of small capacity (1000 in. lbs. maximum) and is especially convenient for use in the case of brittle materials.

HARDNESS TESTING MACHINES

Here is a field in which we have not, as yet, settled on any one type of test and as a result there are many changes. Based on the Brinell method of hardness testing there have appeared several power driven testers and several portable testers, the latter being especially useful for determining hardness of materials when it is impossible to bring the specimen to the machine. Although they fall outside of the last decade, we may include the Vickers hardness tester and the Herbert pendulum hardness tester in this review of progress since their employment has been large in this period. The Vickers machine is of the penetration type (pyramidal diamond indenter) while the Herbert machine makes use of the working of the material under an oscillating steel ball.

During the last ten years we have seen the introduction of the Richle Cloudburst hardness tester, the Shore Monotron and the Rockwell superficial hardness tester, all of which stand as landmarks along the path which may ultimately lead us to a single type of hardness test.

DYNAMIC TESTS

Fatigue—With the increase in speed of moving parts, with demands for lighter parts and for greater economy, greater importance is being attached to combined stresses, secondary stresses and vibration. In consequence, tests to determine the action of materials under repeated loads have been developed. The old time fatigue test was slow and time consuming. To overcome this objection to this test several high speed fatigue testing machines have been produced, among them the Krouse, the R. R. Moore and most recent—the DeForest high frequency fatigue machine which, in addition to the advantage of high frequency (100-300 cycles per second) offers the convenience of using a specimen which does not have to be machined. The specimen is vibrated as a simple beam, supported at the two nodes, in its natural frequency. The load is applied at the end of the specimen by electromagnets, excited by alternating current.

Impact—Several innovations appeared in this field, one of the most recent being the Variable-Velocity impact testing machine developed at the Watertown Arsenal. Results of its use indicate that materials exhibit entirely different results under impacts and low velocities, but more work must be done before final judgment can be pronounced on its utility in the testing field.

Another recent introduction is the Carpenter Torsion Impact testing machine which is making a strong bid for a place in the testing field. Since in the torsion test the outside fibers reach their ultimate stress first, this machine is extremely sensitive to surface conditions and therefore is useful in studying the effects of surface treatments such as carburizing, nitriding, etc.

Vibration—The internal damping capacity of various materials is often of importance, and several machines have been tried to determine this particular property.

the Foeppl Pertz Damping Tester being one of those introduced in the last decade. This field of testing is just in its infancy and no doubt the next ten years will see a vast improvement in methods and in interpretation of test results.

One of the latest dynamic testers is the oscillator type, used to produce vibrations in a structure, thereby permitting detailed studies of various parts under various frequencies and amplitudes.

SPECIAL TESTING MACHINES

So great a number of testing machines were developed for special physical tests in the last ten years that we cannot attempt a review. Among the most recent is the Tour Marshall Stiffness Tester, used for testing thin sheet, strip, rod and wire, by clamping one end of the specimen and loading as a cantilever beam: visual scales give the resulting loads and angle of bend. Another recent one is General Electric's simple mechanical device for testing the brittleness of silicon steel. Some idea of the number of developments may be conveyed by mentioning that the instrument firms "specializing in specials" cannot be enumerated in this space.

TESTING MACHINE AUXILIARIES

The development of the testing machine has been modest but progressive and has in general followed the demands of industry. Probably a greater development has been made in the attachments and auxiliaries necessary for reading and recording loads and deformations with greater accuracy.

First of all a device for checking the accuracy of testing machines was needed and this was forthcoming in the Whittemore-Petrenko Proving Ring. Though first tried more than ten years ago, it evolved into the present form in the last decade.

After a testing machine has been carefully calibrated, it becomes important that the strain reading instruments be accurate. To this end there have been many developments in recent years: the Whittemore strain gage, the H. F. Moore extensometer, the Kenyon-Burns-Young extensometer for sheet metal testing, the Tripolites sheet metal extensometer, the Cartridge Telemeter, the Whittemore flexure plate strain gage, the Tuckerman optical strain gage . . . and many others—all developed to the end that deformations may be more accurately and conveniently measured.

In the field of automatic equipment the Southwark-Emery stress-strain recorder has been developed to a high state of perfection.

SPECIAL INDUSTRIAL TESTS

No single brain could hold the details of all the special tests conducted in all of our industries; nor do time and space permit a complete survey of the field. We shall have to rest content with a few mentions.

The industrial use of the X-ray has developed rapidly in the last ten years, so that inspection of welds, castings, etc., now has become a routine. This subject is covered in a special article in this issue; we record here the important fact that with the use of X-ray equipment certain established types of testing can be eliminated altogether.

General Electric has recently developed a number of testing devices for applications met with in the electrical manufacturing industries: an electrical instrument for indicating the silicon content of sample strips of magnetic sheet steels; a wet tensile strength testing machine for testing saturated papers; a gum tape testing machine; a tear testing machine for varnish cloth and paper tapes; an apparatus for determining iron in asbestos by magnetic analysis of the sample; an apparatus which tests electrical sheet steel for core loss.

Many of the defects of glass are visible flaws; others such as invisible "strains" often are detrimental. Numerous polariscopes have appeared, designed to detect these "strains" qualitatively; the General Electric Glass Strain Analyzer was recently developed to give directional and quantitative as well as qualitative indications.

The great developments in radio in the last decade have led to the production of many instruments for testing in this particular field.

In the electrical field in general, there have been many developments, too many in fact to list them all here. Leeds & Northrup have recently introduced a new insulation resistance test set, a modified Schering bridge for measurements of specific inductive capacity and power factors of dielectrics, and an apparatus for power factor measurements by the phase defect compensation method for high-voltage production tests of power cables. They also brought out in 1928 the phototube type sphere photometer which eliminated the personal element when making comparisons between test lamps and a standard lamp.

One of the outstanding developments has been the cathode ray oscillograph. Although this is discussed in another article in this issue, it must be mentioned here as a testing instrument. Its use in the testing field is just beginning but it appears to have many possibilities.

The last decade has seen more attention paid to the effects of noise on the human race then ever before. The losses due to noise in our every day life are just beginning to be evaluated. Many cities are campaigning for a reduction in noise; architects, engineers and manufacturers are collaborating in providing quieter homes, offices and factories. Scientific solution of the many problems encountered in the study of noise depends upon its accurate measurement and there have been developed for this purpose several sound meters. General Electric, General Radio and other firms recently produced sound level meters for the quantitative measurement of noise and the analysis of the acoustic spectrum of sounds.

The paper industry, rapidly becoming standardized from raw materials to finished products, has many testing devices which belong exclusively to that industry and which have developed as demands for more uniform quality have grown. Arthur B. Green brought out an automatic and a laboratory slowness test apparatus for freeness and consistency of the stock, and a Standard Sheet Mold. R. Fuess Inc. introduced many new instruments for testing paper (especially newsprint) among them the Bekk Smoothness and Porosity Tester, a paper hardness tester and a scratch tester for determining the abrasive constituents in paper. The Thwing-Albert Instrument Co. introduced an electro-hydraulic tensile and elongation tester and the Elmendorf Tearing Tester, a basis weight scale and many other special instruments.

The oil industry is another which has many tests peculiar to itself. To name only a few of the tests made we might list, specific gravity, color, viscosity, carbon residue, flash, emulsification, sulphur, corrosion, vapor pressure, penetration and loss on heating. Many of the instruments for these tests have been introduced in recent years.

Hydrogen-ion concentration measurements are particularly important in some industries. Leeds & Northrup, Central Scientific and other companies developed portable and other industrial (rather than "laboratory") forms of instruments for measuring pH and oxidation reduction potentials.

Continued on page 52

A DECADE of PROGRESS in INDUSTRIAL X-ray Inspection

By CHARLES S. BARRETT

Member of Staff, Metals Research Laboratory, and Lecturer in Metallurgy, Carnegie Institute of Technology, Pittsburgh, Pa.

ALTHOUGH most of the fundamentals of X rays and X ray equipment have been known for years, it is only in the last ten or twelve years that X-ray radiography has come into its own as a fully accredited method of testing. In the metallurgical field its general acceptance was closely related to the development of high-pressure steam power plants and oil refining equipment; manufacturers and users of this equipment demanded thoroughgoing inspection, especially of the castings and welds. X-ray inspection proved perfectly suited to the demands from the very start, and soon the A.S.M.E. Boiler Code Committee wrote radiographic inspection rules into their codes for the construction of power boiler drums, unfired pressure vessels, and pressure-vessels for the petroleum industry. The Bureau of Navigation and Steamboat Inspection, and the U.S. Navy, as well as various foreign agencies also began writing specifications that included radiographic inspection. There can be little doubt that this official recognition of the method has been one of the principal factors contributing to the rapid increase in the number of industrial installations of X rays, for when the boiler code was adopted in 1930 there was only one X ray unit in the country devoted to weld inspection, while two years later there were 11, four years later 24, and six years later 30 in use for this purpose. Wide adoption of the method for weld inspection went side by side with increased application in the foundry, and a great variety of miscellaneous applications were found. A partial list of these uses might be of interest to the reader:

Marine equipment, including ships' boilers, Diesel motor parts, torpedo equipment, pressure tanks and tubing and propellers; railroad equipment such as locomotive boilers, high-pressure vessels, welded beams in bridges and turntables, and reinforced concrete structures; petroleum refining equipment; steel cables; castings; forgings; welds; soldered and brazed joints; laminated wood and other aircraft parts; plastics moulded into complex shapes and with internal embedded parts; war materials, including shells and fuses.

X rays are also used for such miscellaneous purposes as fitting shoes, detecting fraudulent paintings, inspecting fruit for signs of damage from frost, inspecting golf balls and automobile tires for their internal structure, and for detecting foreign particles in packaged foods.

While the radiographic applications are more widely known than other X-ray methods, a full classification should also include X ray diffraction, by which the internal atomic and electronic structure of solids, liquids and gases is being revealed, X ray therapy that is so important in the medical field, and X ray irradiation of plants. Applications in all of these fields have grown in number during the last decade.

Coincident with the expanding use of X-rays in industry there have been satisfying developments in X ray equipment design. The 1920's saw 300 kv. radiographic installations take their place beside the 200-kv. and 250-kv. units, and now there are quite a number of 400 kv. units. Nor has this increase in operating voltage been at the expense of portability of flexibility, for even 400 kv. outfits are made to be moved around in the field in the inspection, for example, of welded joints in penstocks for large dams. Equipment for physics research and for medical purposes has gone to still higher voltages, numerous outfits operating in the range above 600 kv.

During the last decade the art of radiographic inspection by gamma rays from radioactive materials has been developed and has now become an important supplement to the X ray method. It is being widely used in work where portability is a first requirement, and also for inspecting steel too thick for penetration by X rays, thus nicely supplementing the X ray method.

X ray tube design has undergone tremendous improvement since the early days of the unstable gas tube. While early tubes were so temperamental that an expert was required to get the most from them, present day tubes are as simple to operate as an incandescent lamp. The introduction of the hot cathode high vacuum Coolidge tube was the first great advance, and in the last ten years or so the self protected tubes have followed, with X ray shielding and full electrical protection built into the tube. There have recently appeared tubes with rotating targets that are capable of dissipating great quantities of energy for short times. Some of the more advanced tube designs have used the cascade principle with the tube divided into sections.

The manufacturers of fluorescent screens for X ray use have been steadily improving their product, increasing the fluorescing power of the salts used, providing more serviceable methods of mounting the salts, and introducing the new zinc sulphide screens which are much more efficient for long wavelength X rays.

In the field of X ray diffraction, the last ten years have produced several new designs of equipment adapted to commercial work, as well as new diffraction tubes for research laboratories. It is possible to purchase diffraction installations completely enclosed in ray proof and electrically safe housings, with outlets provided for the use of two of twelve diffraction cameras simultaneously. Some of these diffraction units are small and readily portable. In addition to the tubes with tungsten and molybdenum targets commonly used for this work, tubes with other metals as targets are available, which are particularly helpful in precision work and research.

APPENDIX I—STANDARDS

By Dr. Lauriston S. Taylor, National Bureau of Standards

In 1925, lack of dosage standards both retarded the proper use of X-rays and exposed the radiologist to unnecessary and dangerous risks. Various standards were proposed in different countries but their differences were as great as 45%. The National Bureau of Standards undertook to establish an X-ray standard in 1925. This standard employed for the first time the guarded field principle which permitted the construction of small ionization chambers free from most of the errors and uncertainties of the earlier types. In 1931 this standard was transported to England, Germany and France where comparisons were made with the foreign standards. As a result of this work, international agreement on X-ray standards was reached for the first time. As a corollary to this work, new devices were developed for absolute ionization current measurement and the control of X-ray tube voltage. There are now in use in various parts of the world about 15 guarded field standard X-ray ionization chambers and about twice that number of N.B.S. shielded high voltage voltmeters for potentials up to 200 kv.

With the advance in X-ray voltages, the National Bureau of Standards has installed a 500-kv. X-ray plant with the necessary auxiliary equipment. A new type of ionization chamber is now employed. It is likewise of the guarded field type, but operates under high pressure. It is so designed as to overlap the low voltage X-ray regions and extend into the supervoltage regions, thus making possible for the first time a direct measurement of the entire range of high energy therapeutic radiations with a free air ionization chamber.

APPENDIX II—BIBLIOGRAPHY

The American Society for Testing Materials held a symposium in 1936 on applied X-rays, and published the proceedings as a book that should be of interest and value to every practicing engineer. "Symposium on Radiography and X-ray Diffraction Methods." The reader is referred to this book for details in the many branches of the subject that have received a mere mention in this survey article. (C. S. Barrett)

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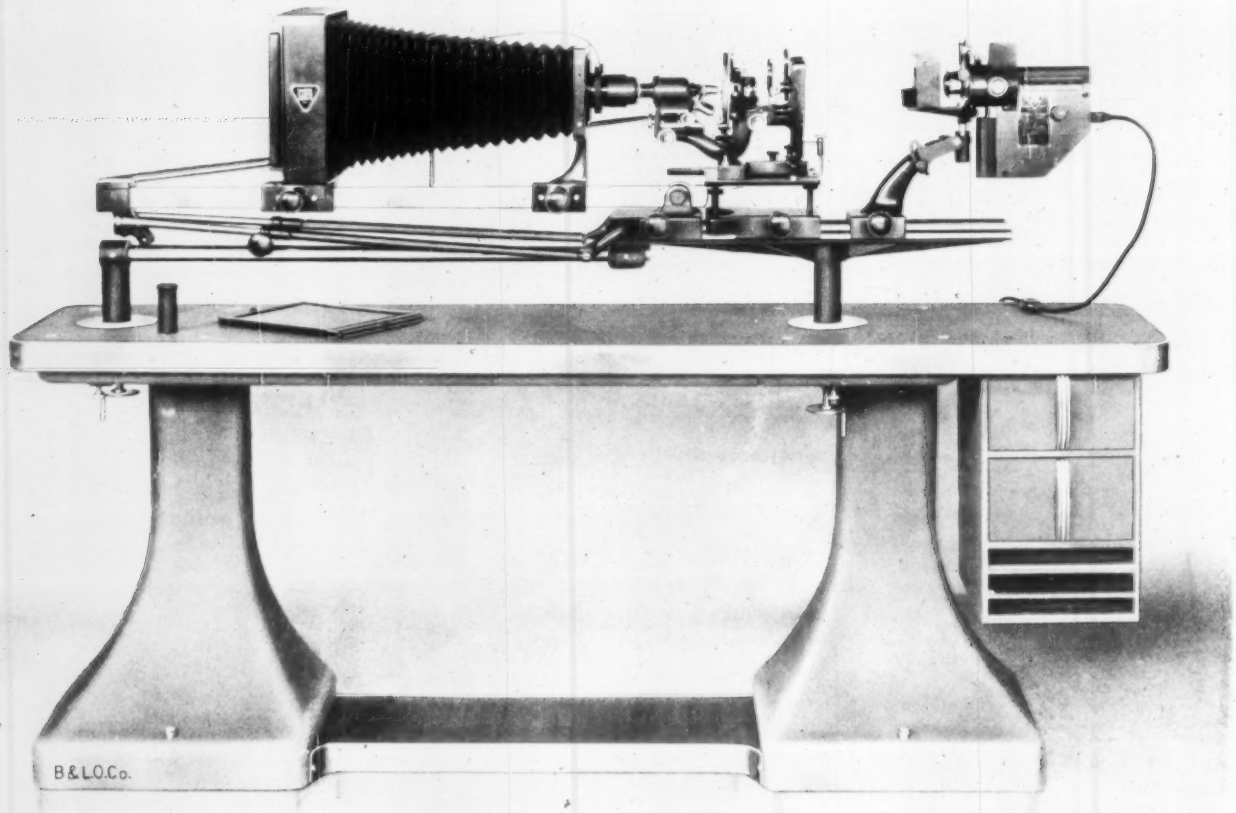

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A DECADE *of* PROGRESS *in*
Laboratory Instruments and Apparatus

By ARTHUR SCHRODER
Evanston, Illinois

EXCEPTIONAL activity in the laboratory apparatus industry sprang from the business depression. Practically every industry today controls its products through its own testing laboratories or those of its raw-material suppliers. As profits declined and competition grew keener, laboratories were required to find cheaper raw materials and improve products; in the feverish rush to beat the other fellow to the market they demanded time-saving apparatus and . . . the laboratory apparatus industry developed more new instruments during this last decade than in any previous quarter century!

BALANCES

Efforts were directed to developing balances retaining previous standards of accuracy while decreasing the time required for making an accurate weighing. The chain weight type—markedly improved by direct-gear drives on the chain-elevating mechanism, giving smooth, positive motion free from back-lash—has found a real place in routine analysis. Some of these have a rotating dial which makes the position of the chain more readily apparent.

Weighing has been speeded up also by the air dash pot and air vane damped balances, as well as the magnetically damped balances. Of these, the air dash pot has come into prominence in the control laboratory, while the air vane type is preferred for more precise analytical work. Magnetically damped balances seem to have lost some of the popularity they enjoyed for several years, possibly because some of the magnetic "attachments" marketed several years ago could not do all claimed for them. These damping devices all have real time-saving merit, and in understanding hands should soon become as commonly used as the more standardized analytical balances.

In the field of dead weight balances the keyboard type has established itself as "the fastest and most accurate balance of the day." Many of these have seen hard use in chemical laboratories, twenty-four hours a day, month in and month out, requiring no more care than the usual cleaning. While still somewhat expensive, they are to be seen in growing numbers in laboratories. Some are now available with the chain attachment for all weights below 100 mgs. The notched beam balance (also of the dead-weight type) is well suited to routine analysis and is rapidly becoming popular. Perhaps the use of riders of metals of higher wear resistance than the brass now in use may extend the useful working time between the necessary rechekings of the weight of the riders.

Needless to say, balances with all sorts of combinations of these time-saving devices are available.

Within the last few years there have appeared several microchemical balances, all making strong bids for the—as yet—limited market.

Balance weights and weighing technique likewise have been materially improved. With keener demand for more accurate weighings has come a better understanding of the inherent errors. Today the air in analytical balance cases is maintained at a low humidity to prevent condensation of moisture on the weights. Numerous balance-case dehumidifying devices, all essentially air-dehydrating material, have been developed. For extremely dry and cold localities static discharge devices, such as a container of a radioactive mineral, are used. The advent of microchemical analysis has made the air conditioned, constant-temperature and constant humidity balance room, with only reflected diffused light around the balance, an actual necessity.

A better understanding of the technical aspects of chromium plating has virtually eliminated all changes in chromium-plated weights due to hydroscopic salt formation under the knob joint. Improvements in lacquer technology have removed the quondam objection of changes in weight of lacquered brass weights due to humidity variations. Most of the lacquered weights of reputable manufacturers now pass the National Bureau of Standards' "time" test for humidity effects. Sheet tantalum has been shown to be satisfactory for laboratory weights below one gram. This has allowed an appreciable reduction in costs of many sets of weights. Stainless steel weights have become available, although their value does not yet seem to be fully appreciated by the average chemist. Quartz weights for use as basic standards have also been made available at fairly reasonable prices.

The National Bureau of Standards has changed its policy of standarizing weights and now certifies weights as "Certified as to Tolerance," as well as "Certified with Corrections." This has placed on the market new lines of weights which are entirely satisfactory for routine analytical methods. As the labor involved in testing a weight between upper and lower limits of tolerance is much less than determining its actual correction factor, these weights are less expensive and are becoming popular. For precise work, however, the "Certified with Correction" weights are being used.

The National Standard Weight, "National Prototype No. 20," was carefully earned by the Assistant Director of the Bureau, Dr. E. C. Crittenden, to the International Bureau where it was again compared with the International Standard Weight. The new value shows that our Standard has been gratifyingly constant; the apparent change, at two parts in a hundred million comes close to the limit of attainable accuracy."

CALORIMETRY

The Parr adiabatic calorimeter, with its well nigh everlasting Illium body, has apparently become the basic instrument in industrial calorimetry. The peroxide type has been improved mechanically. The oxygen type is now available with two valves, so as to facilitate analysis of the gases evolved during the combustion.

A new member of this family, the A.S.T.M. calorimeter, meets the new specifications for methods of testing coal and coke and for determining sulphur in petroleum oils. While mentioning Illium, now that it can be rolled into sheet forms, who can tell what the next decade will bring forth from this?

Gas calorimeters have not been improved much this last decade. The Junkers type is still the standard. Several hot-wire type calorimeters appeared on the market but they are "plant" rather than laboratory instruments, so will not be described in this review.

COLOR AND TURBIDITY MEASUREMENTS

Color measurement had been based on visual comparison, hence subject to personal training, eye defects of the observer, etc. With the introduction of the spectrophotometer the light emitted by, or reflected from, an object can be split up into its spectral components, and these in turn quantitatively measured by a phototube or

photocell and, if desired, actually recorded. Instruments of this type were brought out by General Electric (Prof. Hardy's) Bausch & Lomb and Eimer & Amend. While still requiring a degree of skill in their operation, they nevertheless have reduced color measurement to a more definite quantitative, recordable and reproducible basis.

Numerous new color comparators designed for specific purposes employ light sensitive devices and direct-reading electrical instruments. In some instances amplification by radio tubes is employed.

Several of this type have been developed for use in the clinical diagnostic laboratory and, while apparently adequate for that service, are naturally not univeral in application.

Turbidimeters and reflectometers operating on this same general principal have appeared within the last few years. The turbidimeters, such as the Wagner which is recommended for cement particle size measurement, employ a modification of the Tyndall beam effect and photoelectrically measure the light reflected from the suspended particles. The E & A Photoelectric Color Comparator for both color and turbidity comparisons, and the Cenco Photelometers, typify such recent instruments.

The reflectometers measure the light, usually plane polarized, reflected from a surface and compare it to some commonly accepted set of reference standards.

The Nigrometer, for measuring the relative "blackness" of carbon blacks by measuring their reflecting power as compared with that of a standardized black reference tile block, seems to have solved, at least for a time, one of the serious color problems of the paint and rubber industries.

The B & L Exton Scopometer is recommended for colorimetric and turbidimetric determination of sulphur in coal, cement, boiler and drinking water, biochemical and clinical analysis, etc. It uses four Wratten filters of rather narrow wave-length spectral transmission in the red, blue and green ranges, comparing the light transmitted through the solution under observation with that through the filters which have been calibrated against known solutions. A built in means for adjusting the illumination level or brightness of the field materially extends the usefulness of the instrument.

Many other color comparators, modifications of the Duboscq type, have appeared.

Color comparators based on visual comparison are practically where they were a decade ago, except for mechanical improvements and for the introduction of more nearly standardized reference glasses. The basic working standard of color comparison is still the Lovibond series of glasses. One laboratory has consented to standardize these for quite a reasonable figure. As a result the edible and petroleum industries now have standardized reference glasses. The brewing industry established its standard several years ago and it is understood that national adoption of the standard, at least for beer, is progressing rapidly.

The U. S. Geological Survey Color and Turbidity Comparator has also been improved. This now employs Lovibond glasses as the reference standards instead of the platinum chloride, cobalt nitrate solutions originally recommended by Whipple for determining color of potable and industrial waters. For turbidity, however, suspensions of 200 mesh silica in water are still used. Perhaps standardized turbid glasses may be developed for this and similar turbidimetric measurements within the next decade.

Color glass filters of practically any desired wave-length transmission or absorption have been marketed by one large American and one foreign glass manufacturer. The number of filters is quite large and by combinations of them exceedingly narrow spectrum bands of light transmission are now available. Other manufacturers supply filters made of dyed gelatine and dyed celluloid, usually between glass plates, to effect the same general result. To enable such filters to be used for best results, standardized sources of light must of course be available. "Daylight" electric lamp bulbs, and daylight glass filters for use with the present day standard 60- and 125-watt Mazda lamps, are now available at reasonable prices. These meet the requirements of most routine colorimetry. For most precise comparisons, filters of special spectral transmission, closely approximating the standard "mean northern, cloudless sky, noon daylight at 15 degrees north latitude" are now available, although still somewhat expensive.

Numerous attempts have been made to correlate the various systems of color nomenclature which have arisen in recent years. While several color value conversion tables have been published, tending to bring some semblance of order out of chaos, they more than ever emphasize the need for a more thorough-going standardization of the entire science. The oil industry is particularly active. The N.P.A., the Tag-Robinson, True Color and Optical Density systems are now being investigated with a view toward numerically interrelating measurements on the Union, Robinson and Duboscq colorimeters.

In the field of testing of color fading, Atlas Electric have materially improved their carbon-arc Fade-Ometer and have incorporated humidity and temperature control of the atmosphere surrounding the exposed samples. National Carbon recently announced a complete accelerated-testing unit for the rapid testing of paints, lacquers, etc., using a highly-concentrated carbon arc as the aging medium.

While the recently-formed Color Society is still too young to have made its influence felt, its varied membership includes artists, ink manufacturers, representatives of the graphic arts industries, textile colorists and dye chemists, as well as physicists. With this background and its already expressed willingness to cooperate with other technical organizations interested in color, it ought to aid materially in solving the problems of color measurement.

CENTRIFUGES

Centrifuges are almost foolproof now. Their present sturdy construction has so minimized mechanical failure accidents that only the old timers ever consider that a centrifuge might let go. Streamlined design of heads and accessory parts has increased effective speeds, while rubber cushion suspension of the motor has virtually eliminated vibration while the centrifuge is coming to speed. Standardization of parts now permits the use of some of the larger centrifuges for practically all the usual analytical procedures, and has eliminated the need of a separate centrifuge for each test. Auxiliary heating and refrigeration is available for the larger centrifuges. While vacuum centrifuging has been reported as a means for selective crystallization, more work is required before its possibilities can be appreciated.

The centrifuge microscope of Bausch & Lomb has already solved more than a few knotty research problems. Its future as a research tool seems assured. The Babcock milk and cream centrifuge, the Board of Health serum centrifuge and the A.S.T.M. oil centrifuge have been standardized throughout and are established in their respective industries. One American manufacturer has just announced a new angle centrifuge which seems to promise the solution of a few of the settling problems and breaking of emulsion problems of industry. Perhaps a model capable of handling larger tubes than the 10 ml tubes now being used may aid in the rapid determination of small percentages of water in oils, emulsions, etc.

DISTILLATION APPARATUS

Marked progress has been made in the automatic control of water stills operating on gas, steam and electricity. The Barnstead, Precision and the Stokes companies each supplies practically fool-proof full automatic units which produce remarkably pure water. Double and triple distilling units were brought out for producing so-called "conductivity water" and water suitable for use in intravenous injection. The replacement of the tin lined domes of the smaller Stokes stills with Pyrex glass domes is but one of the many refinements made by manufacturers in order that users may produce better water.

Serious study of the distillation of organic material by a number of investigators has resulted in the appear

ance of an entirely new series of glass distilling columns, among which the Brunn Bubble Cap and the Penn State Fractionating Columns stand out.

The Brunn column is the laboratory counterpart of the bubble cap towers of the petroleum industry. The Penn State column is an electrically heated jacketed column with built in reflux condenser mounted to one side of the top.

The newer Podbielniak centrifugal fractionator distills up to 400 ml. per minute of reflux plus product at over 200 plate efficiency.

GAS ANALYSIS APPARATUS

The Orsat type, while still holding the field for routine flue gas analysis, is rapidly being replaced for precision analysis by the more elaborate and accurate types, such as the Bureau of Mines type and the Shepherd Bureau of Standards types. The Haldane Air Analyzer, in its numerous modifications, still leads for air analysis, while the Van Slyke manometric type is making rapid inroads into those fields requiring the handling of minute quantities of gas. Five or six manufacturers are marketing all of these. The interchangeable unit type of apparatus, in which all parts are standardized as to size, shape, etc., has made a real name for itself in the larger industrial laboratories. Convenience in operation, as well as increased accuracy, characterize all late models.

Gas analyzers for specific purposes have also been developed. The Yandell Henderson Syringe Type Analyzer is recommended by Eimer & Amend for the analysis of atmospheres of oxygen tents, etc. Special outfits have also been developed for the determination of noxious fumes in lacquer spray booths, although no standardization of either method or apparatus is discernible at present. More work is urgently needed here. Several new gas analyzers of the thermal conductivity type, such as that of Gow-Mac, were announced — for plant, rather than laboratory, use. The Edwards Gas Density Balance has been improved mechanically and is still the most universally used instrument in its class. Fuess has recently announced a much smaller density balance, employing electromagnetic means to restore equilibrium. Analysis of the so-called uncondensible gases is now an everyday procedure with the Podbielniak fractionating type of gas analyzer. The original low temperature analyzer has been supplemented by a high temperature unit and the combination covers practically the entire range of these gases, including even the propanes and butanes. The Podbielniak [illegible] is now available with automatic control.

HYDROGEN ION AND OXIDATION-REDUCTION POTENTIAL

The relative merits of the various methods of determining hydrogen ion concentration have been argued heatedly. The trend today seems to be toward using the colored indicator solutions with either colored liquid or glass reference standards for routine testing, except when strongly oxidizing or reducing conditions prevail and when the natural color, excessive turbidity and excessive salt concentration of the solution to be tested tend to interfere, under which conditions the trend is toward electrometric systems.

A dozen or more glass electrode outfits appeared in the last decade. Some of them fell by the wayside, probably by reason of mechanical weaknesses and improper electrical balance between components of the system. The survivors are doing fine work. The type of electrode to be used is still an open question. The antimony electrode, suited to certain specific applications, seems to have been oversold in some industries, hurting the prestige of the electrometric types. The quinhydrone electrode has been proven quite satisfactory for general use up to a pH of about eight to nine. The new glass developed by Corning for this work has made possible the manufacture of glass electrodes reproducible and interchangeable for most practical purposes. Most outfits today consist of a calomel reference electrode, a quinhydrone hydrochloric acid electrode surrounded by the glass membrane itself and a galvanometer across a Wheatstone bridge or potentiometer. With infinitesimal currents flowing — and with no flow when using a null method — the electrical instruments must be of the finest. Standard cells and potentiometers had been available for years and have reached high perfection today. The precision galvanometer required being of necessity delicate and expensive, attempts have been made to circumvent its use, several manufacturers bringing out radio type amplifiers; the customers seem satisfied. The question of optimum size of glass electrode to use in order to overcome the asymmetry potential remains unanswered. However, in spite of all the problems unsolved, one company reports at the time of writing (late December) that a recording hydrogen ion apparatus has been in daily use in a paper mill for a number of months, improving product as well as saving plant operating costs.

Oxidation reduction potential measuring equipment is following much the same line of development. Eastman and the British Drug Houses now offer extensive lines of colored liquid indicators covering an rH range from about 3 to 27. In this country the trend is toward the use of the glass electrode systems, modified as need be, to meet specific conditions of test. Just how much this new type of control may aid industry is beyond guess, but its possibilities seem limitless.

HYDROMETERS

Many new hydrometers were developed for specific purposes. Most are regular types with special scales. Alcohol, calcium chloride, sodium chloride, glue, syrup, milk, sugar, tanning liquors and anti-freeze materials all have special hydrometers developed for them. Boiler water hardness measurements have come in for particular attention. The Stromberg Motoscope Corp. has been active here. The Aquatron, Pyknotron and A.P.I. Thermotron are all modifications of this general idea. The U. S. Internal Revenue Pattern hydrometers have been improved slightly, with emphasis on accuracy and mechanical strength. Recent developments include streamlining to facilitate cleaning, and the "wrapped in cellophane" Rascher & Betzhold dairy hydrometer which, because of its cellulose acetate coating around the glass, can be dropped to the floor without breaking.

MICROSCOPES

To do justice to all improvements made in microscopes and accessories during the last ten years would require an entire book. As most of these were adequately described in *Instruments*, a few notes will suffice. All the major microscope manufacturers have redesigned their products for greater rigidity and freedom from vibration in use. Supports are stronger, stage space has been increased, and most parts have been standardized so that one can start with a simple, inexpensive scope and gradually add additional equipment as need arises, without purchasing a new microscope for each new field of microscopy undertaken. Numerous new accessories were announced by Bausch & Lomb and Spencer. Among noteworthy new instruments is the B & L. Petrographic scope with built in devices for holding all accessories ever required in complete petrographical and chemical investigations, including polarized light equipment. Metallographic outfits were likewise improved and refined. The new B & L. equipment now has provision for bright field, polarized light and dark field illumination. Magni

fications from 1— up to the highest possible with oil immersion objectives is possible. A new highly concentrated illuminating system, all metal streamlined construction, factory alignment of optical system and binocular eyepiece, all tend to bring this into the front rank of metallographs. What has been done in America along this line has been paralleled abroad.

A fascinating recent development is the Polaroid medium recently described in *Instruments*: simple disks used in pairs give all the effects obtained by crossed polarizing and analyzing prisms. While not recommended as the equivalent of the highly refined optical glass polarizer, it does cheaply solve many problems.

SPECTROSCOPES AND SPECTROGRAPHS

With the last trace of an impurity now becoming the most important ingredient in a new alloy, the search for the needle in the haystack becomes a reality and the modern industrialist demands the tools to find it in the shortest possible time. The last decade has established spectroscopy on as firm a footing as quantitative chemical analysis, with the difference that spectrographic methods of analysis usually require less time than the corresponding chemical analysis. With this demand has come the development of new spectroscopes, spectrographs and accessories. Bausch & Lomb, Gaertner, Hilger and Zeiss have redesigned practically their entire lines of spectroscopic equipment. While the optical systems remain about the same, the major changes have been the substitution of metal for wooden parts which did on occasion warp and give trouble, and the incorporation of many mechanical devices to save time and to aid in the operation of the instruments themselves. Some of the instruments are so designed that both glass and quartz optical systems can be interchanged. Accessory equipment, such as the sector photometer, line density comparator, spectrum line projector and spectrum measuring microscopes, have been improved considerably.

TEMPERATURE MEASURING APPARATUS

The last decade has seen real advances in the simplification and standardization of temperature measuring devices. Thanks to the splendid standardization work of such committees as D4, D15 and E1 of the A.S.T.M., and to the corresponding coöperating committees of the American Standards Association, the National Bureau of Standards, the A.P.I., and the other technical societies like the Association of Official Agricultural Chemists and the American Oil Chemists Association, the number of thermometers formerly required in the average testing laboratory has shrunk from hundreds to dozens, with consequent lowering of operating costs. Today thermometers are more accurate and uniform in dimension than ever before. Manufacturers have been quick to realize the importance of such standardization and, with increased quantity production made possible, have passed on the saving to the consumer. Fine Bureau certified thermometers are now available at about one half former prices.

Two new improvements in thermometer design reduce errors of observation: (1) Color contrast, exemplified in various ingenious constructions such as the Palmer, the Tag Hespe and the Moeller, all using bright red; (2) the Taylor "Binoc" with a corrugated face on the stem. This refracts the light impinging on the mercury and on reflection from it is again refracted, permitting the mercury to be read from an agle at least three times as wide as was formerly possible.

Another innovation is the Rasher & Bertzhold thermometer with a cellulose acetate film on the outside of the glass, rendering it "shatter proof."

Recording thermometers, pyrometers and temperature controllers being discussed in another "Decade of Progress" article, suffice it to report here that all such "industrial" instruments find more numerous applications in laboratories today (and more important uses) than they did when *Instruments* was founded. In the laboratory field, however, temperature control devices have received almost as much attention as all other forms of control devices put together. The virtual perfection of the bimetallic strip thermoregulator was a great advance in the right direction, but as it is somewhat limited in operating range and is usually subject to a time lag, more sensitive controls were wanted. Today the mercurostatic regulator, of the hermetically sealed mercury in glass type, is the most popular for accurate work. American Instrument, Cenco, H-B Instrument, Rascher & Betzhold, and others, all make reliable regulators. Due to fouling at the contacts and the inevitable loss of sensitivity, numerous trick wiring diagrams were devised. No one really solved the problem until the mercury switch with suitable relays came to the rescue. Now, baths are in daily use in which temperature is being held to ± 0.01 C. month in and month out. Several companies supply constant temperature baths of this type. Some are applying this same type of control to drying ovens and incubators.

Constant temperature ovens have also been improved by the installation of more sensitive controls and better internal construction and design, with a view to utilizing natural convection currents; and forced-air circulation has been added to the larger ovens. Humidity control is also available on a few sizes of these ovens. The complete line is available in stainless steel models.

VISCOMETERS AND CONSISTOMETERS

With the better understanding of the laws operating in viscous and plastic flow has come a thoroughgoing investigation of all the instruments for measuring viscosity and consistency, and an attempt to reconcile the results obtained when using different instruments. At the present time the instruments in use are: The Saybolt Universal and Saybolt Furol, standards in petroleum industry; the Engler, still used for some pitches, emulsions and some paints and paint vehicles; the Stormer, for paints, silicates, starches and pyroxylin solutions; the Mac Michael for anything from water to glues, gelatines, asphalts, varnishes and greases; the Gardner Holt tubes for varnishes; the Gardner consistometer for nitrocellulose solutions, heavy lacquers, liquid resins, some greases; the A.S.T.M. consistometer for heavy greases; the Herschel consistometer for heavy oils and asphalts; and for more general use the Fenske, Ubbelohde, Vogel Ossag and FitzSimons, and similar modifications of the Oswald pipette; and the Hoeppler or falling-ball types. Added to these are the falling co-axial cylinder consistometer for asphalts, the asphalt penetrometer and its modifications for testing the tenderness of meat and of peas, cooked fruit, etc.; the Blum gelometer for testing gelatine; and the Gilmore needles for determining the setting time and consistency of cements.

All of these have been redesigned or improved within the last few years. While, obviously, they all cannot be used interchangeably, certainly some could be eliminated. The A.S.T.M. and the A.P.I. are now investigating many of these and, perhaps with the help of the National Bureau of Standards, the Society of Rheology, the Portland Cement Association, and the paint and varnish industries, some semblance of order will come. A milestone along this road was the symposium on consistency held last June by the A.S.T.M., at which ten papers described the various tests and instruments in use, and possible means for simplifying this subject.

Continued on page

A DECADE *of* PROGRESS *in*
Time Instrumentation

By M. F. BEHAR

EVEN before 1928 there was a bewildering diversity of industrial timers, time recorders, time switches, sequencing devices, process cycle controllers and elaborate coordinated instrumentation or "centralized brain" systems. Today, this diversity is so much greater that *Instruments* had to give up its search for a "user writer" to handle this "Decade" subject. We shall merely touch the high spots: detailed discussions of methods and instruments introduced before 1932 have been published[1] in these columns.

Under the broadest interpretation, all timepieces are "time indicators," all instruments producing records with time as one of the coordinates are "time recorders," and all piano-players and sign-flashers are "automatic sequencing controllers." The importance of the time element in industry, however, has led to the development of numerous special instruments related *primarily* to time. We shall deal only with such instruments.

I INDICATING and REGISTERING

Ten years ago most time-indicating instruments were manually-operated. Today the majority (in industry) are attached or connected to the equipment under study. Some require that the single hand or series of pointers be manually set back to zero; in others the pointer automatically flies back to zero when the instrument is re-started.

For the longest intervals of industrial interest the visually registering instruments are generally called hour meters or time meters or counters. Some have dial registers; others have cyclometer ("direct-reading") registers. Electrically connected elapsed-time registers of this class were brought out in the last decade by Central Scientific, Cramer, Esterline Angus, G-E, Warren Telechron, Westinghouse and Weston. Hasler brought out the "Running-time Meter" purposely designed for *mechanical* drive from the machine under study in order to make its registrations tamper-proof. Most of these time registers have minutes (or tenths) for their smallest divisions; a few have the counter driven faster, so that its last digit represents seconds (or hundredths as in the Cenco).

For smaller intervals and for registering seconds and tenths the stop-watch (manually started and stopped) has blossomed forth into many modern forms: electrically- and spring-driven; pocket, bench and switchboard; single- and multiple-hand; operated by direct pressure or from a remote specially-designed switch. Forms are too numerous to describe; makers are too numerous to name individually.

A variant of this class is the process indicating and signalling timer, many forms of which were brought out by Stromberg Electric. Their standard model has two hands or pointers: one is manually set for the desired interval; the other starts from this setting point, travels *back* to zero and causes a contact to be made in the signal circuit when it reaches zero.

For registering (not recording) still smaller intervals, "cycle counters" were introduced by G-E, Standard Electric Time and Westinghouse. As suggested by the name, the ultimate division is a single a.c. cycle.

Now we're getting into the field of chronographs and oscillographs (dealt with under "Recording") but Westinghouse has invaded this field with a *visual* indicator, the Cycle Splitter.

II RECORDING

Industry needs few ionization-research oscillographs producing diagrams readable to microseconds; fewer alarm-system operation recorders with twelve-month charts; but between these extremes its growing requirements have induced instrument-makers by the scores to bring out hundreds of different types of time-recording instruments in thousands of forms. Thousands of kinds of industrial applications call for records on round charts as large as 12" and as small as 1"; on 20" wide strip-charts, on $\frac{1}{4}$" tape-charts and on 3"×5" card charts; on charts with time divisions and on blank charts or films; on charts that move at constant speed and on charts that advance by jerks like adding-machine tape; records which are not "charts" though autographed on paper; records which are not "graphs" though correlating time with other data; record in the forms of continuous lines, interrupted lines, jog-lines, thick and thin lines (with or without medium-thick to show the intermediate condition); cross and oblique lines, "staircase" lines, spirals, triangles, dots, tamper-proof perforations or photographs, indelible inks and inkless impressions, printed numerals and letters . . . and others, no doubt—for this is the first attempt to classify the forms of time-recorder records.[2]

Since each form of record requires an *ad hoc* mechanism to produce it, it is evident that the many time recorders now on the market could be classified on this basis and that the result of such a classification would be a complicated table.

Even more complicated would be a classification of applications together with recommended types of time recorders.

One group of applications deserving special mention lies within the field of motion and time study. It is within the last decade that special recorders for these studies have begun to appear.[3]

An easy and useful classification of time recorders is into (1) single-record and (2) multiple-record types. An attractive feature about time recorders of the chart types is that the number of recording pens is limited only by the size and design of the recording instrument case. There are also multiple-switching possibilities as with temperature recorders whereby a number of pieces of equipment may be successively connected to the recorder, either manually or automatically. Then, too, there are combination instruments which record on one chart several time records pertaining to one piece of equipment. As a rule these combination instruments furnish only one strictly time record, the others being speed, temperature or other "measuring" records. An important exception to this rule is the work-analysis type, designed for manual operation by time-study men and providing on one chart time records of the various elements of a manufacturing or assembling job.

Most time recorders are continuous running and their charts are divided into days, hours, minutes, etc.: into intervals of civil time. Special instruments are started simultaneously with the equipment to which they are connected, and their charts, when divided into usual time units, are not positioned with regard to time of day. Regular instruments, too, can be used in this way, by simply disregarding time of day and positioning the chart at "12" or zero when a process is begun.

Chart-less Recorders. New models of the Calculagraph and of other time stamps were brought out for industrial use.

Operation-time Devices. For attachment to recording instruments which already embody time-drive charts various "chronograph pens" (Esterline Angus), "time-operation pens" (Tag), time punches (Consolidated), etc., were brought out.

"Vehicle" Type Recorders. Cramer, Teteo, Ohmer, Pittsburgh Taximeter, Service, U. S. Recording and other firms brought out inexpensive running-and-idle-time recorders, most of them with small "disk" charts, most of them vibration-operated, most of them designed for commercial vehicles, but all deserving to be considered for application to machine tools, etc.

"Service Man" Types. These small portables were all brought out in the last decade. The Friez uses 3"×5" card charts driven by a spring clock, weighs 3 lbs. and slips into your overcoat pocket. The Practical Instrument line is of the electric clock type, with 4" round charts.

Plant Types, Constant-speed Charts. This group includes so many recent designs that we can only mention a few. Bristol's new models include a 20-pen strip-chart recorder and also an

[1] Vol. 4 (1931): The Field of Time Instruments in Industry, pages 279-285; Indicators, pages 309-311; Recorders, pages 312-322; Controllers, pages 323-332.

[2] And we're doing it from notes we made for a lecture in 1931, supplemented by recent catalogs of only ten instrument firms.

[3] This enormous field has hardly been scratched. It will no doubt be served by specialized types of instruments and these, we predict, will be operated from keyboards. This is a safe prediction to make, for the two portable recorders which have already been designed for motion and time-study men for motion and time-study men have their pens operated by the pressure of fingers on keys: a recent German instrument has three such pens, and Professor Ford's "Acheloiscraph" (*Instruments* Vol. 8, Dec. 1935, pages 320-321, 347) has five pen-actuating keys arranged to fit the pattern of an adult's right-hand finger-tips. The future instruments will not have three or five keys each connected to one pen and producing a line record, but they will have either (a) thirty, fifty or a hundred keys or (b) a relatively small number of keys—seven—capable however of producing as many distinguishable kinds of thrilling records as there will be kinds of thrillers in the future systems based on the work of Frank and Lillian Gilbreth, or as many kinds of time-elements in various future systems of job analysis. See editorial on August 1935 *Instruments*.

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all-electric single-pen round-chart instrument producing a spiral record, the chart-rotation period and the number of turns in the spiral being both optional. The Esterline-Angus line, which, though only strip-charts, was the most extensive when the decade began, was further extended, chiefly by further diversification of chart-drive mechanisms. Foxboro,[4] Taglia[illegible] and Taylor likewise introduced new features in both their electrical and mechanical round-chart lines. These five firms now offer both portable and panel-mounting models.

Chronographs are beginning to find various plant uses, though primarily designed for laboratories. Cambridge, Cenco, Fuess, and Gaertner all made refinements in their lines. Gaertner brought out printing chronographs which produce, in addition to the record of the device under study, a parallel continuous time scale consisting of three rows of numerals, to hundredths of seconds. The new G-E "Cycle Recorder" is a switchboard instrument for welding-machine applications, but belongs in the chronograph class: records read to single a.c. cycles.

Recorders with Intermittently-running Charts were brought out, chiefly for machine-tool applications, from simple tape-chart models to the elaborate "Chronolog" of National Acme.

Motion Picture Cameras were brought out for industrial time-analysis service, some with microscope attachments[4] and some with accessories for motion study work.[5] For research applications Professor Edgerton's system as embodied in General Radio's camera, neon-lamp and accessories, has made possible the slow-motion viewing of phenomena filmed at thousands of images per second.

III CONTROLLING

Long before 1928 there had been brought out a variety of automatic time control devices from simple time switches and time-delay relays to elaborate coordinated instrumentation systems eliminating the human element from the operation of processing equipment.

During the last decade the real progress has consisted in the geometric progression increase of industrial automatic-timer installations[6] and in such a multiplication of types and makes that even a topical outline and a list of names would exceed the space we have finally allotted.

The only real innovation during the last decade was the amazing increase in the number of successful capacitator charge-and-discharge hook-ups (made possible, of course, by many reliable new types of electron tubes, as well as by the commercial production of previously "special" capacitors).

Some rather weird devices burst forth in recent years and fizzled out like skyrockets because, of the countless timing principles known to science and tried by designers, few lend themselves to embodiment in fool-proof instruments. It's like the artillery time fuze problem: thousands of patents but only the old powder-train fuzes and escapement-clockwork fuzes proving themselves bore-safe and showing negligible percentages of duds. Therefore we salute the capacitor-charge-and-discharge principle on its adoption by industry. It had to be good to displace cam, dashpot, and other principles even if only in the field of single-purpose, small-interval, on-and-off applications.

For multiple-purpose, continuous or "cycle-repeat" applications, of course, cams still reign supreme. This is particularly true in the field of process control where temperatures, humidities, pressures, flows, levels and other conditions must frequently be raised *gradually*, held "on the nose" for a definite time and then lowered *gradually*, all in exact accordance with predetermined time curves. In this field, nothing has taken the place of a set of cams, each cam continuously resetting a condition controller.[7] In some systems of coordinated instrumentation, all cams are on one shaft; in others there is a plurality of camshafts, of shaft speeds and of starting and stopping.

Five firms made (or rather "built") practically all of the few multiple-cam process controllers required by industry before 1928: ATC, Bristol, Cutler-Hammer, Tag and Taylor. They no longer "build" them; they make them in production lots; and so do a dozen more firms because among other reasons "recent years Industry" has been forced to strive toward the ideal of fully-automatized plants . . . of manless factories![8]

[4] See the article on Microcinematography by Henry Roger in *Instruments*, Vol. 8, July 1935, pages 168-169, 195. It contains a table of applications.

[5] These seem to have been misused by some "efficiency experts" whose tactics enraged labor unions to an extent that had international repercussions (Charlie Bedeaux and the Duke of Windsor) but this is not the fault of the designers of these systems.

[6] And it is indeed a sign of Progress with a capital P, this gradual emancipation of those whom politicians (or politicians' ghost-writers) call "slaves of the machine" — which most of us have been at times when we watched gages and clocks and turned valves.

[7] When we say "multiple-cam" we imply also the Jacquard-loom and player-piano-roll principles. These, however, do not lend themselves as well to embodiment in fool-proof, malfunction-proof, *durable* industrial controllers.

A DECADE *of* PROGRESS *in*

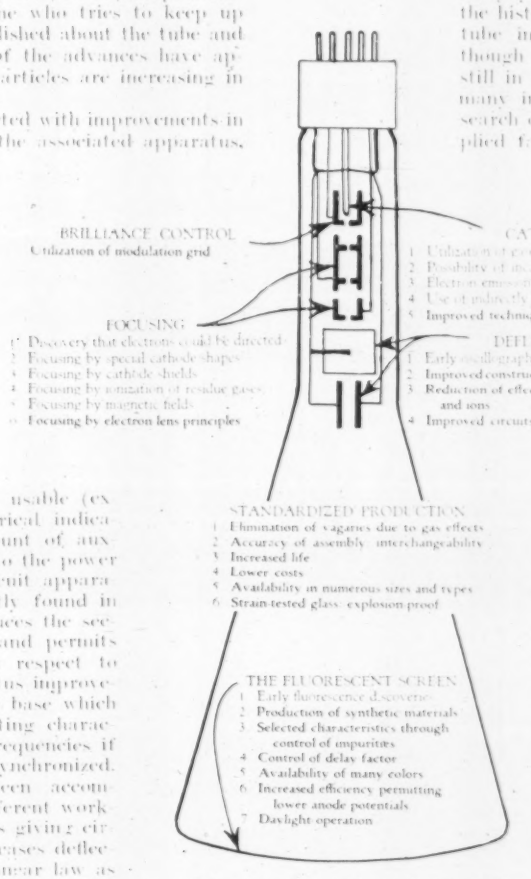
Cathode-ray Oscillography

By RALPH R. BATCHER

Cathode-ray and electronic application consulting engineer, Hollis, L. I., N. Y.

ONE of the major problems of science is the accurate determination of variable effects. One of the outstanding contributions to the science of instrumentation during the past decade has been the universal usage of oscillographic methods, whereby the moment-to-moment levels of rapidly changing characteristics can be delineated with simple means. These variables are to be found in all fields of research, processing, fabrication, testing, inspection, etc. The cathode-ray tube has proved itself valuable as the nucleus of the most convenient oscillographs. Its growing importance is at once apparent to anyone who tries to keep up with the articles that are published about the tube and its applications. Since most of the advances have appeared in the last ten years, articles are increasing in geometric progression!

This rapid development started with improvements in the tube itself, then took in the associated apparatus, and is recently including special devices and methods whereby the usefulness of the oscillograph is extended into fields where heretofore accurate instrumentation was not available. In the matter of the cathode-ray tube itself, the milestones of progress are noted in the chart herewith, where the items in bold face type represent advances made during the past decade.


BRILLIANCE CONTROL
Utilization of modulation grid
FOCUSING
1 Discovery that electrons could be directed
2 Focusing by special cathode shapes
3 Focusing by cathode shields
4 Focusing by ionization of residue gases
5 Focusing by magnetic fields
6 Focusing by electron lens principles
CATHODE
1 Utilization of electron emission
2 Possibility of incandescence
3 Electron emission discovered
4 Use of indirectly heated cathodes
5 Improved technique insuring long life
DEFLECTION
1 Early oscillographic applications
2 Improved construction increasing accuracy
3 Reduction of effects due to stray electrons and ions
4 Improved circuits for magnetic deflection
STANDARDIZED PRODUCTION
1 Elimination of vagaries due to gas effects
2 Accuracy of assembly, interchangeability
3 Increased life
4 Lower costs
5 Availability in numerous sizes and types
6 Strain-tested glass: explosion-proof
THE FLUORESCENT SCREEN
1 Early fluorescence discoveries
2 Production of synthetic materials
3 Selected characteristics through control of impurities
4 Control of delay factor
5 Availability of many colors
6 Increased efficiency permitting lower anode potentials
7 Daylight operation

Important steps in the evolution of the cathode-ray tube. Developments made during last decade are indicated by bold-faced type.

The cathode-ray tube is not usable (except for a few simple electrical indications) without a certain amount of auxiliary apparatus. In addition to the power supply unit, the time base circuit apparatus is the item most frequently found in test set-ups. This item introduces the second dimension to the figure and permits effects to be measured with respect to time. The outstanding apparatus improvements have been: (1) A time base which has more nearly linear operating characteristics, operates at higher frequencies if needed, and is more readily synchronized. These improvements have been accomplished in several ways by different workers. (2) Special timing circuits giving circular movements, or in other cases deflections which follow some non-linear law as desired. (3) More general utilization of standard vacuum tubes in unusual applications, there having been a great variety of new tube types produced during the past decade. (4) Availability of special vacuum tubes to fill unusual needs whenever the need of such designs became apparent to the tube manufacturers. (5) Accurate deflection amplifiers having linear amplitude and frequency characteristics. These items have become the universally accepted parts of a standard cathode-ray oscillograph. In addition we have the electronic commutator or switch in several forms, whereby several functions can be disclosed at once. In another field there have been numerous types of deflection potential converters which transform various physical and mechanical effects into deflection potentials. These have opened up many new fields of research.

Mass production now meets the requirements of radio servicing and other fields; and has lowered costs to a multitude of other users as well.

A list of even the commonest applications would be too long for this brief résumé. The present trends follow several lines of utilization: (1) studies where operations or functions are timed giving an answer in terms as small as a part of one microsecond if need be; (2) studies where the amplitude of some variable effect is investigated utilizing the "inertialess pointer" principle; (3) finally the class of studies of growing importance where the mutual characteristics of two interrelated variables are delineated without having to refer each to a common time base. This traces instantaneously a graph of a single event or, in other cases, with a slight change in the operating technique, a family of curves of a series of events.

The first cathode-ray oscillographs were built some forty years ago and the first three decades witnessed the historic work of a few outstanding investigators in tube improvements and in application methods. Although in many cases the principles they disclosed are still in use, during the last decade there have been so many investigators, working independently and in research organizations, that the developments have multiplied faster and faster. It is not possible to list here those individuals who deserve credit. Many improvements, however, are by-products of work on television, which has attracted the attention of so many investigators.

Many problems in the field of high tension transmission have also contributed information concerning the generation and control of high velocity cathode rays, resulting not only in improvements in the design of all types of oscillographs but also in valuable records of many types of abnormal high voltage disturbances.

The story of electron beams and their utilization is not complete without reference to many adaptations in non-oscillographic fields: high-speed relays with weightless armature, oscillators, the remote control system receivers, magnetic compasses, etc. In another important field of research the *electron microscope* has received much attention. Here an enlarged image of an electron-emitting surface is projected on a fluorescent screen by the emitted rays themselves. While the study of the character of emission surfaces might seem to be rather restricted in practical applications, it is reasonable to expect wider use in microscopical research.

Another device is the electron telescope wherein an image projected on a photoelectric surface, even with invisible infrared or ultra-violet radiation, produces electrons which are focused on a screen so that the original image appears in all its details. The television pick-up camera has made televised outdoor scenes an actuality and, in some forms, it is more sensitive than the human eye.

In the future, industry will find uses for the cathode ray *electron eye*—not the so-called but the real thing at last: not the ordinary photocell which distinguishes only between light and darkness, but a perceptor which sees everything in its true form and relative motions, though not yet in its colors. Moreover, scanned images of views which are inaccessible to ordinary vision are quite possible with apparatus even now available. The next decade will undoubtedly bring industrial television.

Of greater industrial importance, however, will be the uses of the cathode-ray tube as an automatic inspector: not only testing each and every specimen passing along a conveyor but rejecting those outside of the tolerance limits and even classifying those it accepts.

A DECADE of PROGRESS in INDUSTRIAL Electron Tubes

By H. C. JENKS

Engineering Laboratories, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

TEN years ago, available electron tubes were primarily those of radio design. Their capacities were limited by their dimensions and by the types of elements used. It was just about then that industry began to assert its needs for tubes of more rugged construction, greater capacity, longevity, and stable characteristics. Multiplication of types and varieties became marked approximately a decade ago.

Viewed from the vantage point of today, it would seem that this almost explosive expansion was somewhat too rapid: "new" tubes frequently were minor modifications; and many new designs of narrowly limited applicability died of non-use. Contributing to this mushroom growth was the mistake of constructing applications in the light of special tube characteristics instead of adapting circuits to the then existing electronic devices. Fortunately, out of this vast expenditure of energy and money came a few new types which have permitted Electronics rapidly to move into industry and make for itself an undeniable berth in the field of measurement and control.

Early stages of industrial tube development followed high-vacuum design. Bringing out better cathode materials permitted heavier current capacities and suitability for industrial heavy-duty applications. These tubes being of the high vacuum type, their characteristics resemble those of tubes employed for communication reception. The tubes produced included improved rectifiers, industrial screen grid amplifiers, and pentodes. Other adaptations of the high-vacuum principle were the electrometer tube used for measurement and the tubes used for automatic train control, etc.

About nine years ago the invention of certain new types of tubes definitely altered the trend of development and application. Research improved cathode construction still further, making possible the manufacture of tubes with emitting elements of considerably greater current capacity; and the introduction of the "grid glow" or "thyratron" principle, involving the gaseous type of tube, provided a device which met the needs for larger inter-electrode current capacities. The characteristics of these tubes make them particularly useful on a-c. systems inasmuch as the passage of current through the tube when once initiated as a result of grid voltage modification will persist to the end of the particular cycle during which conduction is started, and will be extinguished at the end of that particular half cycle, provided that the grid potential has returned to its original blocking value. These tubes appear quite like the normal high-vacuum device except that because of higher built-in capacities, they usually are larger in size. (Tube arc drop is so much lower that larger size frequently is necessitated by cathode radiating requirements rather than by anode capacity.)

Among the many gaseous tubes brought out during the ensuing years are tubes employing single grids, multiple grids, and some heavy cathodes permitting instantaneous current surges of several hundred amperes without injuring the tube.

SUMMARY OF INDUSTRIAL TUBES

1. HIGH VACUUM

1-a. Rectifiers	2-element (half wave)
1-b. Rectifiers	3-element (full wave)
1-c. Detectors	
1-d. Amplifiers	3-element
1-e. Amplifiers	Screen grid
1-f. Electrometer	
1-g. Train Control	
1-h. High Voltage	Rectifiers

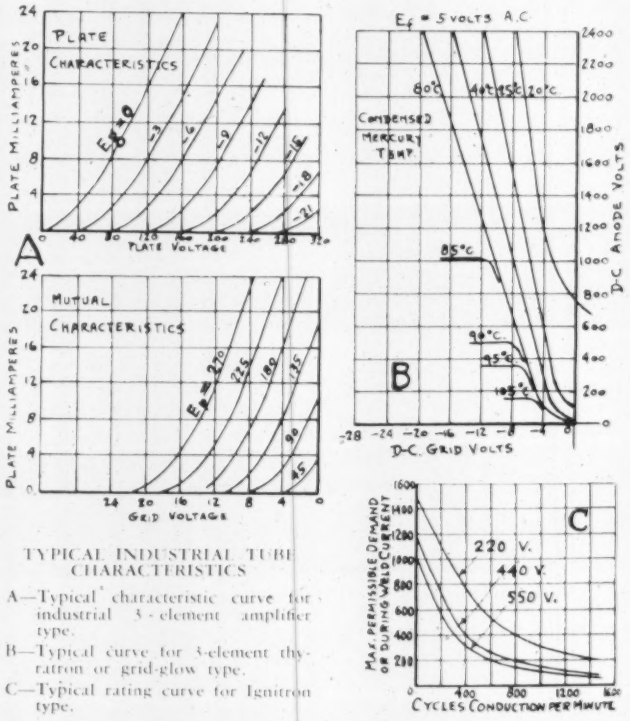
2. GASEOUS

2-a. Rectifiers	2-element (half wave)
2-b. Thyratron	3-element (one grid)
2-c. Thyratron	4-element (screen grid)

These are normally mercury vapor type, glass construction. Modifications comprise noble-gas filling for temperature characteristic improvement, and also metal construction in a few models.

3. IGNITRONS

3-a. Glass construction in smaller ratings
3-b. Sealed-off permanently evacuated metal types for medium ratings
3-c. Steel tank, continuously-evacuated types for large ratings



TYPICAL INDUSTRIAL TUBE CHARACTERISTICS

A—Typical characteristic curve for industrial 3-element amplifier type.

B—Typical curve for 3-element thyratron or grid-glow type.

C—Typical rating curve for Ignitron type.

Both directly- and indirectly-heated cathodes are used. V-shielded directly-heated cathodes are quite popular. A normal modification of this type of tube is found in the hot-cathode mercury-vapor rectifier in which no grids are provided, so that the tube is purely a rectifier.

The normal grid-controlled gaseous type (thyratron or grid-glow) employs mercury vapor as its inter-electrode conducting medium. Others of this type employ inert gases such as helium or argon, with the result that their characteristics remain substantially constant over a wide ambient-temperature range.

Although the grid-controlled gaseous type had many times the rating of the industrial high-vacuum type, there still was a need for a type that could withstand current surges of thousands of amperes. This need was met in 1932 by the introduction to industry of the Ignitron principle of tube operation. The Ignitron employs a cold cathode in the form of a pool of mercury. It has no grid: its control resides in an igniter a resistive element dipping into the cathode mercury. "Firing" is initiated by the passage of current through the igniter into the mercury. Following this current passage, ionization of the tube permits the conduction of load current for the remainder of the half-cycle during which ignition has occurred. In this particular respect, the performance of the Ignitron is similar to that of the grid-controlled gaseous type mentioned above. Paradoxical as it may seem, the early Ignitrons were either tiny or huge: small ones built in glass envelopes; large ones in steel-jacketed chambers continuously evacuated by pumping systems (sometimes built into the chassis). The advent of metal construction in radio tubes made itself felt: virtually all medium-sized modern Ignitrons are of permanently-sealed steel construction. Continuously-evacuated steel-tank Ignitrons, however, are still favored for heavy-duty work.

During the major portion of the past decade, few radio tubes have been applied to industry. However, since the appearance of the above described grid-controlled gaseous types and igniter type, for handling heavy currents, radio tubes of the high-vacuum type are again entering the industrial field as initiating and control media for these heavy-current tubes.

In the above remarks, no reference has been made to type numbers, since there are several manufacturers. The general types are summed up in the brief table herewith. Breakdowns of the general classes would require individual manufacturers' analyses for which there is no space in a general resume of a Decade of Progress in Electronic Tubes.

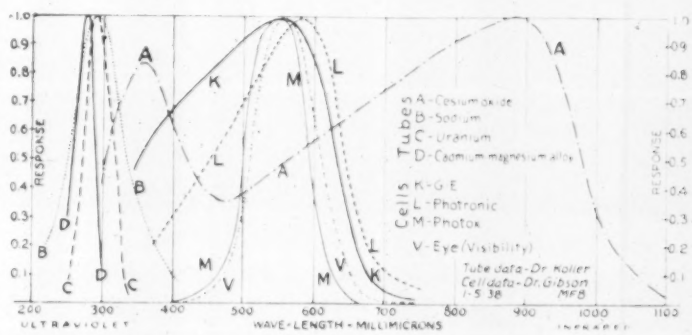
A DECADE *of* PROGRESS *in* INDUSTRIAL

Phototubes and Photocells

By L. R. KOLLER
Research Laboratory, General Electric Co.,
Schenectady, N. Y.

TEN years ago the phototube was a laboratory device. Since then it has grown to be a commonplace and reliable servant of industry, its growth in that decade exceeding that in the four preceding ones—for it was fifty years ago that the photoelectric effect was discovered by Hertz. Within twenty years after the publication of his discovery there was developed a fairly comprehensive theory, which has continued to advance with the growth of modern physics. Lagging behind theoretical advances, the development of the phototube as a practical device stood nearly still until the last decade, during which notable advances were made.

Two or three years after Hertz' discovery, alkali metal phototubes in highly evacuated glass bulbs were made.[1] A marked advance occurred in 1916; Elster and Geitel[2] found that alkali metal surfaces could be made much more sensitive by treatment with hydrogen, to form hydrides. Their alkali hydride tubes were probably nearly as sensitive as any tube available in 1925, about which time the rapid growth of the electron tube art, and inceptive industrial phototube applications, gave the impetus required for new developments.



SPECTRAL CURVES OF REPRESENTATIVE TUBES AND CELLS
Spectral response curves compared with that of the eye (the so-called visibility curve), all arbitrarily made unity at wave-length of maximum response.

The first of these, about ten years ago,[3] was the cesium tube, made possible on a commercial scale by the development of the technique of producing cesium[4] (as well as the other alkali metals) by the reduction of their salts in vacuo. This technique, combined with the growth of knowledge of the behavior of thin films, resulting from studies made about this time[5, 6], gave rise to a cathode consisting of a monatomic film of cesium adsorbed on a silver surface. Although superior to anything previously available, these tubes had a sensitivity of only about one microampere per lumen for vacuum tubes, and five or six microamperes per lumen for gas-filled tubes.

The next step in advance, around 1928[7], was the production of the composite-surface cesium tube which is the type form of most of today's commercial tubes: a cathode consisting of a film of cesium adsorbed on a thin layer of oxides on a silver base. Its most striking characteristic is its sensitivity to the near infra-red portion of the spectrum. Most phototubes are used in conjunction with incandescent light sources. Less than 10% of the radiation of incandescent lamps lies in the visible spectrum; the remainder is in the near and far infra-red. Accordingly, any development which makes phototubes more responsive to infra-red will enable them to make use of this vast and otherwise wasted heat radiation. Tubes of this type have a sensitivity of about five microamperes per lumen for vacuum tubes and fifty microamperes for gas-filled tubes.

The next advance was a further enhancement of the red sensitivity by the deposition of a thin film of silver on top of the composite surface[8]. This results in an increase in the sensitivity of vacuum tubes to nearly 100 microamperes per lumen[9]. Thus, in a decade, the sensitivity of the vacuum cesium phototube has progressed one hundred-fold.

A striking advance which is playing a part in the field of television and may also affect industrial applications is the secondary emission multiplier[10]. In this tube, photo-electrons are made to strike a target and give rise to secondary electrons. By applying the principles of electron optics, several such stages are cascaded and the photoelectric current is amplified a million-fold. Since this is accomplished within the same envelope as the photo-cathode, it may be considered to come within the scope of this article.

With the increase in ultraviolet radiation applications there has been a corresponding need for phototubes sensitive to ultraviolet. These have long been available in expensive quartz bulbs or bulbs with quartz windows. Within the last decade, however, the development of special ultraviolet transmitting glasses has made it possible to produce tubes in glass bulbs which respond to radiation just above 2536 A.U. By sputtering[11] and by evaporation[12], surfaces of various metals have been prepared which respond to different portions of the ultraviolet spectrum.

In addition to these outstanding advances, there have been many improvements both in construction and in technique, not great in themselves, but which taken altogether have resulted in great gains in phototube quality.

In the field of selenium resistance tubes there has been a trend to thin films rather than the heavy layers formerly used. This, together with other improvements in technique, has resulted in more sensitive and more stable cells.

In the field of photovoltaic cells[13], also called blocking layer or barrier cells, it is difficult to speak of the "improvement"—within the last decade, for these cells have practically come into existence within this period. The photo-sensitive properties of cuprous oxide[14] have been known for a long time, but little practical use was made of them until recently. In 1930 there appeared the first commercial form of these cells[15]. Many others have followed. The two forms most widely used in this country are cuprous oxide on copper[16] and selenium on iron[17]. The former has a sensitivity of approximately 175 microamperes per lumen, and the latter as high as 690 microamperes per lumen. Both curves lie well in the middle of the visible spectrum. In both cases the earliest cells had large temperature coefficients and fatigue effects. Improvements in technique have made the temperature and fatigue effects practically negligible, and these newcomers in the photoelectric field have found a constantly growing number and variety of applications in measurement and control work.

There is no reason for thinking that the present devices represent the ultimate in the photoelectric art. Since on the average only two light quanta in one hundred cause the emission of photo-electrons, there is ample room for improvement. It is quite possible that the development of the phototubes and photocells is not nearing its completion but is only beginning.

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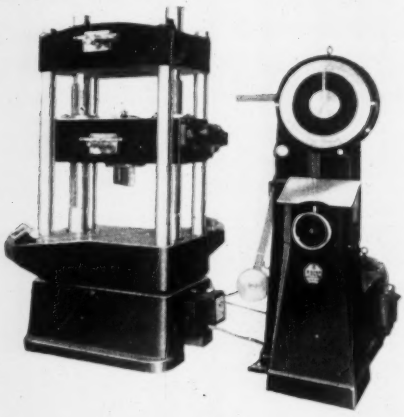

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Concluded from page 50

Special testing apparatus for many other industrial purposes were developed in the past ten years. Central Scientific brought out the Cenco-Menzee Cement Soundness Testing equipment for testing structural cements and a special photelometer for determining particle size and surface area of materials of sub sieve fineness. Tagliabue has introduced the Tag-Heppenstall Moisture Meter for determining the moisture content of grains, another one for determining the moisture in tobacco, a gager's test set, and an alcoholic-content ebulliometer.

The instruments and machines discussed in the preceding paragraphs are largely designed for permanent installation in industrial testing departments. Occasionally it is necessary to take the testing equipment to the job rather than bring the material to the laboratory. An outstanding example of this is the Sperry Detector Car, equipped with electrical devices which record defects in rails as it moves over a railroad track. Another Sperry product is the Gyro Track Recorder by which a graphic record of track irregularities under full impact of the train load, and the riding qualities of different types of motive power and equipment, may be made.

This is but a brief outline of a few developments in the testing field in the last decade. An attempt has been made to touch on a few widely separated fields in order to show that testing is now being done in every line of work. Nothing escapes the testing engineer: everything we eat or wear or use for our pleasure or our work comes under his eye. Standardization is the goal . . . and therein may lie a danger. Too much reducing to fixed procedures may hamper the development of new ideas and act as a drag on the wheels of progress.

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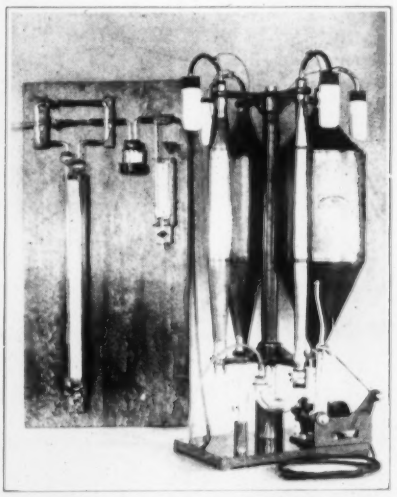

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Concluded from page 75

MISCELLANEOUS

A big step forward, based on little things but saving time and apparatus cost, has been the appearance of extensive lines of glass burettes, extraction flasks, bottles, stopcocks, etc., both of Pyrex and chemical resistant grades of glass, all with the "standard taper" ground joints which permit parts to be interchanged without regrinding. One manufacturer is supplying an extensive line of these with metal-coated plugs.

The Jena Glass Works has developed a new type of precision bore glass tubing of various cross-sectional shapes, with the inside dimensions kept within a tolerance of ±0.001 mm. Round, square and hexagonal cross-section tubes are stock items, with inside dimensions of 0.5 mm. minimum to 50 mm. maximum. Many are in daily use in colorimeters and pH comparators of the Hellige type.

Filtration has been advanced by the Jena Glass Works of Schott & Genosen developing highly alkali- and acid-resistant glass and using it in their special fritted glass filters. These may now be had in six different porosites for use with most precipitates. Special colored filter disks are also available to order, for use with colored precipitates. A complete line of analytical apparatus in regular and microchemical sizes is now available from stock.

In addition to general-application instruments, there have been developed many designed for specific industries, such as the wear and abrasion testing machines for rubber, textiles, lacquers, electroplating, leather, etc.; apparatus for measuring the glare, opacity, porosity and stiffness of paper; covering power of paints; drying time of varnishes; dielectric constant of insulators; gum forming tendencies of gasolines; the particle size analyzer for cements, pigments and the like; the G-E lamp shade mercury vapor detector, and the new ebulliometers for determining alcoholic content. Some are no doubt covered in the "Industrial Testing" article. This article has discussed only a few high-lights in a field crowded with interesting innovations. A real tribute is due those who designed the instruments which made possible this Decade of Progress.

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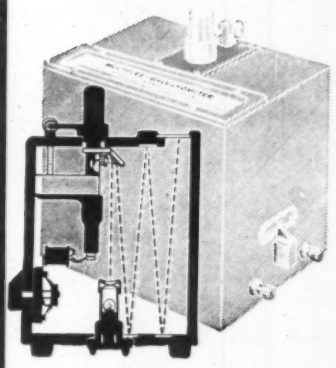

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